CommONEnergy

DELIVERABLE 5.1

Systemic solution-sets

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CommON*Energy*

Re-conceptualize shopping malls from consumerism to energy conservation

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Contents

Executive Summary

This document gathers the work performed within Task 5.1 of CommONEnergy project.

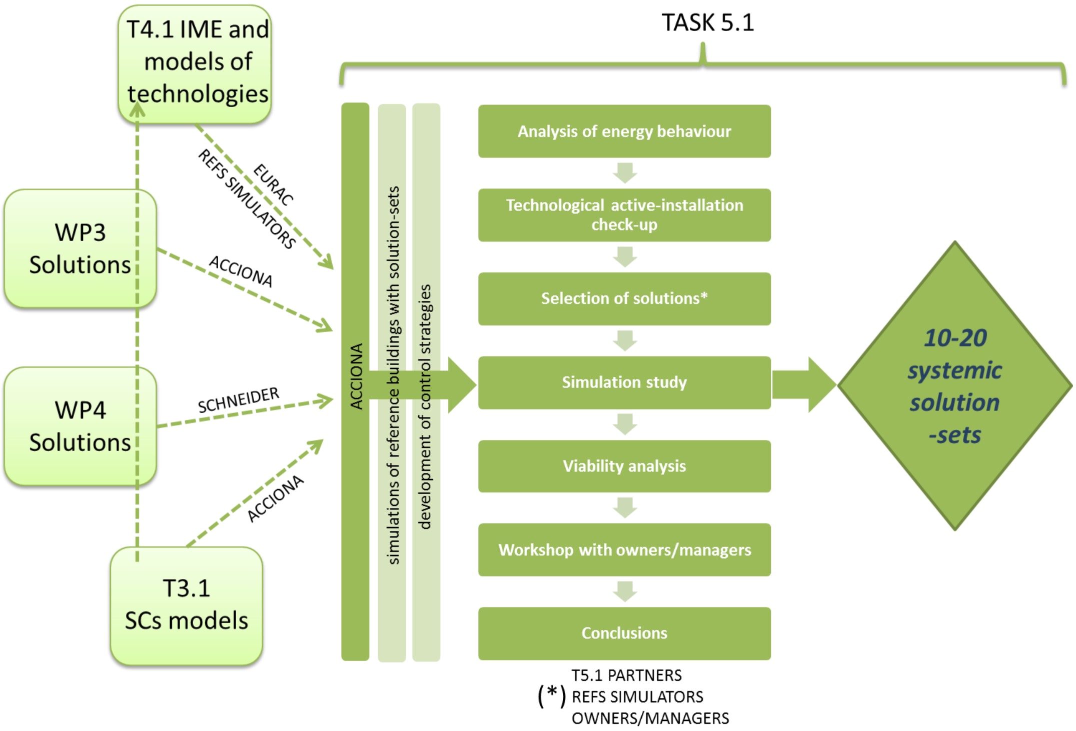
Among the objectives of the CommONEnergy project is the development of architectural and energy systems retrofitting solution sets to reduce building energy needs, enhancing the overall energy efficiency to provide appropriate indoor environmental quality (IEQ) and exploiting renewable energy sources (RES).

The objective of Task 5.1 was to define 10 to 20 combined energy solution sets for deep retrofitting of shopping mall. The work of this task aimed to gather the outputs from previous WPs and tasks, in order to merge them into a holistic approach, focused on the definition of 10 to 20 most suitable solution sets for both target buildings and demo-cases proposed within the project. Moreover we identified and defined universal concepts for specific building categories, based on energy saving principles and validated by specific energy benchmarks, to be used as reference tool at the pre refurbishment stage. For that purpose, a set of different activities were carried out following a replicable methodology per each reference building aiming to study different possibilities of solution packages, suitable per each shopping mall, depending on their boundary conditions.

The different reference buildings studied are listed in the following table (the first three buildings correspond with the three demo-cases, where specific retrofitting packages were actually implemented) and their location is shown in the above map.

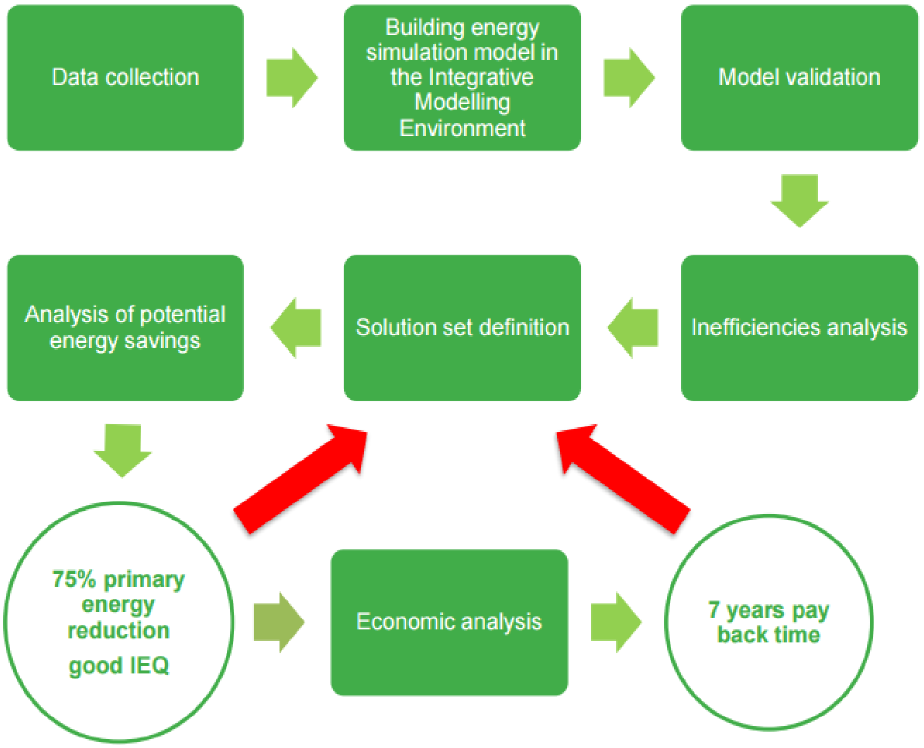
Building	Manager	Location
Mercado del Val	Municipality of Valladolid	Valladolid (Spain)
City Syd	Storebrand	Trondheim (Norway)
Coop Canaletto	Coop Estense	Modena (Italy)
Coop Valbisagno	Coop Liguria	Geneva (Italy)
Brent Cross	Hammerson	London (UK)
Katané	Ipercoop Sicilia	Catania (Italy)
Donauzentrum	Unibail Rodamco	Wien (Austria)
Pamarys	Baltisches Haus	Silute (Lithuania)
Studlendas	Baltisches Haus	Klaipeda (Lithuania)
Waasland Shopping Center	Devimo	Sint Niklaas (Belgium)
Grand Bazar	Devimo	Antwerp (Belgium)

The methodology shows the interaction among different WPs which will give many inputs for the configuration of the aimed solution-sets packages. Such work methodology is summarized in the scheme below.



As shown in the workflow above, the starting point of task 5.1 needs inputs from different tasks in WP3 (passive solutions and Trnsys building models) and WP4 (active solutions and Trnsys technologies models). In addition, for the definition of the solution-sets, further useful information is necessary, such as KPIs defined in D2.5 and D5.2. Cost-Effective solutions will be achieved by combining different aspects to be analysed.

WE proposed an original methodological framework for the definition of solution-sets and set of KPIs, which were used as objective to fulfil. A solution-set can be defined as a combination of passive and efficient active measures, utility equipment and energy generation technologies. The measures are integrated looking for and exploiting synergies among HVAC, lighting, refrigeration, energy use as well as for building correlated services (parking, RES harvesting and local energy production etc.). The methodology we used for the definition of solution-sets is schematized in the following workflow.



The solution sets shall accomplish three specific targets, which are:

- 75% energy consumption reduction (compared to the baseline).
- 7 years payback time (PBT).
- To keep an acceptable Indoor Environment Quality (IEQ) level

Reference shopping centres representatives provided us with data about reference building features, operation modes and measured data to build an energy simulation model. Collected data and information on reference shopping centres allowed us to build building energy models representing the actual state of the buildings. Each building energy model was validated against measured data in order to guarantee that it represents as close as possible the actual building behaviour and it can be used as baseline for the solution set performance evaluation. In this activity, some buildings have been calibrated with yearly bills, others with the coordination with reference contacts and others could not be validated due to the absence of suitable data (in that scenario, standard ratios were used as inputs for the simulation model).

Once the baseline was finalized, an analysis process starts in order to identify inefficiencies and possibilities for the implementation of new solutions.

Therefore, a first solution set definition was chosen in a qualitative way. The following step was to proceed with the numerical study using the simulation model and integrating the solutions in order to evaluate the energy savings achieved. As it has been explained, the first objective in this case was to obtain a 75% of primary energy reduction. After achieving this objective, next step was to evaluate from an economic point of view whether the solutions set has a 7-years payback. At this stage, it started an iterative process with the evaluation of energy savings and economic analysis.

The process ended (and the solution-set was defined) when the combination of solutions and energy efficiency measures reduced the maximum energy consumption with a limit of 7-years of payback time.

Energy and economic study we performed for each reference building was divided in different steps, as reported in the following.

- **Technological active-installation check-up**: in order to have a clear and detailed understanding of where and how the different facilities operate to match the building loads, defining which is the current situation of the building in terms of heating/cooling equipment.
- **Analysis of energy consumption. Baseline simulation**: identification and analysis of the current building energy behaviour after simulation process. This is the baseline as starting point for the following steps. In case suitable data were available, performing of model calibration.
- **Selection of suitable solutions**: taking into account the characteristics of each shopping mall (climate, energy profiles, priorities, inefficiencies, availability of free space or easy installation, etc.) proposal of solutions that could be suitable for each building, showing their replication potential
- **Energy savings**: energy results obtained after simulation analysis implementing the different solutions proposed with the objective of reducing the primary energy as much as possible (facing the 75% reduction as objective).
- **Economic analysis**: to prove the profitability of the investment in energy retrofitting with the implementation of the different solutions. After this step, the solution-set should be defined.
- **Final considerations**: summary of previously obtained results, assessing foreseen results and the outputs from simulations for the identification of the solution-set.

At the end of the activity, 14 solution-sets were identified.

	Solution-set	Reference building	Expected energy savings/payback
1	**Geothermal heat pump** **Modular climate adaptive multifunctional façade** **Effective artificial lighting equipment + control strategies**	Mercado del Val (Valladolid – Spain)	70% PE / 6.8 years
2	**Efficient lighting system and controls** **Efficient appliances** **Natural ventilation** **Insulation**	CitySyd (Trondheim – Norway)	61-66% PE / <7 years
3	**Efficient lighting system and controls** **Efficient appliances** **Natural ventilation** **Insulation** **Photovoltaic plant**	CitySyd (Trondheim – Norway)	75% PE/ 12-13 years
4	**Efficient lighting system and controls** **Replacement of refrigeration cabinets** **Building envelope thermal improvement** **Reflective coating** **Improving HVAC efficiency** **Coupling HVAC and refrigeration**	Coop Canaletto (Modena – Italy)	55% PE / 7.3-11 years
5	**Efficient lighting system and controls** **Refrigeration – CO2** **Heat pumps water loop** **Natural ventilation** **PV plant**	Coop Valbisagno (Genoa – Italy)	40% PE / 7.2 – 11.1 years
6	**Efficient lighting system and controls** **Appliances replacement** **PV system**	Brent Cross (-UK)	55% PE / 7 years or 75% PE / 19.4 years
7	**Efficient lighting system and controls** **Heating and cooling setpoint management** **Demand control ventilation (DCV)** **Natural ventilation** **PV plant on gallery roof and parking canopies**	Katané shopping centre (Katania – Italy)	58% PE / 5.1–6.8 years
8	**Efficient lighting system and controls** **Efficient appliances** **Cooling set point control** **Natural Ventilation** **Photovoltaic plant** **Revolving doors**	Donauzentrum (Vienna – Austria)	26% PE / 3.2-3.8 years
9	**Effective artificial lighting equipment + control strategies** **Building envelope thermal improvement** **Heat recovery and heating set point management** **RES integration (PV panels + Wind turbine)**	Pamarys (Lithuania)	63% PE / 6.3 years

Solution-set		Reference building	Expected energy savings/payback
10	**Effective artificial lighting equipment + control strategies**	Studlendas (Lituania)	50% PE / 5.7 years
11	**Building envelope thermal improvement** **Heat recovery and heating set point management** **Façade shadings for solar control**	Waasland (Sint-Nikklas – Belgium)	60% PE / 6 years
12	**RES integration (PV panels + Wind turbine)**	Waasland (Sint-Nikklas – Belgium)	60% PE / 6 years
13	**Efficient lighting and control** **Appliances replacement** **Cooling set point management** **Heat recovery system** **Photovoltaic plant**	Grand Bazar (Antwerp – Belgium)	40% PE / 5 years
14	**Efficient lighting and control** **Appliances replacement** **Cooling set point management** **Heat recovery system**	Grand Bazar (Antwerp – Belgium)	36% PE / 4.9 years

1 Definition of solution-sets. KPIs and methodology

Among the objectives of the CommONEnergy project is the development of architectural and energy systems retrofitting solution sets with the aim at reducing building energy needs, enhancing the overall energy efficiency to provide appropriate indoor environmental quality (IEQ) and exploiting renewable energy sources (RES).

A solution-set can be defined as a combination of energy conservation (passive solutions) and energy efficiency measures (active solutions) which can include the technologies developed within the project and other conventional solutions (i.e. heat recovery system, thermal insulation, etc.). The measures are integrated looking for and exploiting synergies among HVAC, lighting, refrigeration, energy use as well as for building correlated services (parking, RES harvesting and local energy production etc.).

The individual solutions developed in the frame of the project are the listed inTable 1-1 and Table 1-3. Table 1-2 and Table 1-4 report their potential application for the retrofitting of reference buildings used in this study.

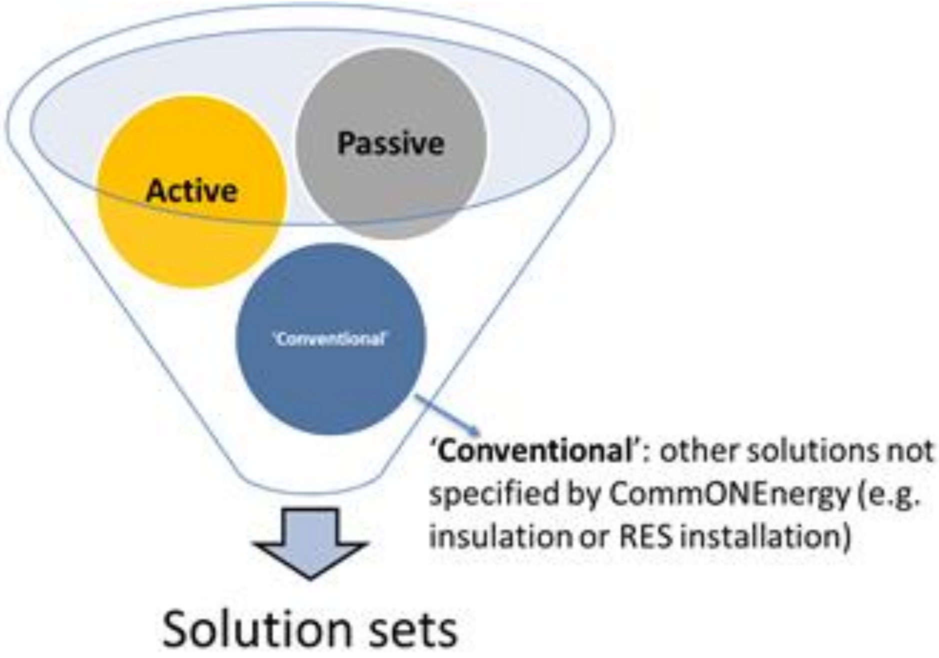


Figure 1-1. Definition of solution-set

Table 1-1. Description of passive solutions developed within CommONEnergy

Technology	List	Brief description
Ventilative cooling	Enhanced stack ventilation	automated openings located in the skylights to enhance stack ventilation
	Wind catcher	wind catcher integrated into light tubes to naturally ventilate shops
	single-sided ventilation	automated openings located in the facade to exploit natural ventilation
	Fan assisted ventilation	increased mechanical ventilation rates to reduce cooling need
Thermal zoning optimization	radiant panels	air conditioning in the refrigeration cabinets zones by means of radiant panels
	full air with air supply diffusers for anti-mist formation	use of specific air diffusers to prevent mist formation on cabinet doors
Modular multifunctional climate adaptive facade	configuration 1	bottom and top openings with integrated PV in the bottom part and shading system
	configuration 2	ventilator louvres with integrated PV and shading
Green integration	surrounding trees	change air characteristics (temperature, humidity, oxygenation etc) in building's surroundings
	intensive/active vegetated roof	bigger plants, higher initial and exploitation costs, weight- up to 1300kg/m², soil substratum thickness min. 30 cm
	extensive/passive vegetated roof	smaller plants, lower costs, weight- 50-300kg/m², soil substratum thickness min. 15 cm
	direct vegetated wall	the greening system uses the facade as a growing guide
	indirect vegetated wall	the greening system and the facade are separated with an air cavity
	indoor greenery	usage omitted in CommONEnergy
Smart coatings	IR-reflective/absorbing	All possible combinations from these characteristics may be selected.
	self-cleaning	
	insulating	
	anti-mold	
Daylight strategies	external solar lamellas	Static opaque lamella, adjustable to climate and indoor requirements by different lamella distances
	modular roof, Solar harvesting grid	Grid structure which harvests direct sun while redirecting in uncritical directions (avoiding glare), is part of an overall concept, called modular roof, which can react to project-specific conditions (e.g. position of sale area, climate,…)
	light-tube	Daylight system which guides daylight from the roof into room by excellent light transmission properties, improvement in visual comfort and benfits for higher turnover
Thermo-acoustic envelope components	flexible mat without finishing	
	flexible mat with additional soundabsorbing layer	
	flexible mat with additional finishing	
	flexible mat with additional soundabsorbing layer and with additional finishing	

Table 1-2. Possible applicability of passive solutions developed within CommONEnergy into reference buildings

		Applicable to the reference building:										
Technology	**List**	**CS**	**ME**	**GE**	**BC**	**KA**	**DO**	**PA**	**ST**	**WS**	**GB**	**MO**
Ventilative cooling	Enhanced stack ventilation	X	X			X	X			X		
	Wind catcher	X						X				X
	single-sided ventilation			X	X			X			X	
	Fan assisted ventilation							X				X
Thermal zoning optimization	radiant panels		X	X		X	X	X	X	X	X	X
	full air with air supply diffusers for anti-mist formation		X	X		X	X	X	X	X	X	X
Modular multifunctional climate adaptive facade	configuration 1		X		X		X	X	X	X	X	X
	configuration 2			X		X				X		
Green integration	surrounding trees	X			X			X	X	X		
	intensive/active vegetated roof			X			X			X		
	extensive/passive vegetated roof	X		X	X			X		X		
	direct vegetated wall			X	X		X	X	X	X		
	indirect vegetated wall			X	X		X	X	X	X		
	indoor greenery											
Smart coatings	IR-reflective/absorbing	X	X	X	X	X	X	X	X	X	X	X
	self-cleaning	X	X	X	X	X	X	X	X	X	X	X
	insulating	X	X	X	X	X	X	X	X	X	X	X
	anti-mold	X	X	X	X	X	X	X	X	X	X	X
Daylight strategies	external solar lamellas	X	X	X	X	X	X	(X)	X	X	X	(X)
	modular roof, Solar harvesting grid	X		X	X	X	X			X	X	
	light-tube	X		X	X	X	X	X	X	X	X	

[CS]=CitySyd; [ME]=Mercado del Val; [GE]=Genova; [BC]=Brent Cross; [KA]=Katané; [DO] = Donauzentrum; [PA]=Pamarys; [ST]= Studlendas; [WS]=Waasland; [GB]= Grand Bazar; [MO]= Modena

Table 1-3. Description of active solutions developed within CommONEnergy

Technology	List	Brief description
iBEMS	HVAC + shading + artificial lights + natural ventilation + monitoring	The monitoring system provides the required communication means between the installed modules and respective sensors. It incorporates control rules of higher and lower level for the optimization and usage of the systems.
Smart integration in energy grids	Micro-grid without RES participation	
	Micro-grid with RES participation	
	Micro-grid as stand-alone system with RES participation	
	Micro-grid as stand-alone system with RES participation	
	Heating with common storage use and refrigeration heat recovery	
	Solar cooling & heating & DHW supply	
	Heating with common storage use and refrigeration cold storage	
	Solar cooling & heating & refrigeration sub-cooling	
	Cogeneration for heating and electricity	
	Generation of heating and electricity with RES	
	Cogeneration for heating and electricity with RES	
	Trigeneration for heating, cooling and electricity with cogeneration system	
	Generation of heating, cooling and electricity with RES	
	Trigeneration for heating, cooling and electricity with RES	
	DHW supply with RES participation	
Electrical Energy storage	PV + battery	use of PV+battery storage to increase self-consumption for the all shopping mall consumption or to cover dedicated load or EV-charger
	PV + H2	H2 for hydrogen car mobility or with FC for electricity consumption
	PV + Storage + electromobility	Use the storage for Ev-charger
Refrigeration system	Transcritical system for warm climate (Genova Solution)	Transcritical system with features able to manage high ext
	Transcritical system with HVAC Integration	The refrigeration system actively recover the waste heat o
	Transcritical system with Solar Integration	Solar and refrigeration system work togheter to maximize
	Transcritical heat pump for Heating and/or DHW	Heat pump with natural refrigerant producing heat and DH
	Thermal storage to manage refrigeration load peak	Fire-prevention tanks used to shave cooling peak request.
	Integral refrigeration based on water loop within the refrigeration syster	Integral cabinet with water condensed system and a water
	HVAC&R water loop distribution inside building	Water loop system linked with w/a heat pump, balanced t
Artificial lighting systems	General Retail Lighting (GRL)	Energy-efficient light source: LED, precise distribution by 7
	projector/mirror system	Energy-efficient light source: LED, improved maintenance
	LED wallwasher	Energy-efficient light source: LED, precise illumination for
Building Integrated Electric Mobility system	Charging stations	The EV Charging station provides a refueling point for elec
	Electrolyser and storage	The hydrogen storage system tranforms available power t
	Hydrogen mobility	Parallel to the previous description the stored Hydrogen c
	Battery for industrial vehicles	The chemical storage system using batteries is applied for

Table 1-4. Possible applicability of active solutions developed within CommONEnergy into reference buildings

Technology	List	CS	ME	GE	BC	KA	DO	PA	ST	WS	GB	MO
iBEMS	HVAC + shading + artificial lights + natural ventilation + monitoring	X	X	X	X	X	X	X	X	X	X	X
Electrical Energy storage	PV + battery	X		X	X	X	X			X		
	PV + H2	X		X	X	X	X			X		
	PV + Storage + electromobility	X		X	X	X	X			X		
Refrigeration system	Transcritical system for warm climate (Genova Solution)			X		X						
	Transcritical system with HVAC Integration		X		X		X	X	X	X	X	X
	Transcritical system with Solar Integration			X		X						
	Transcritical heat pump for Heating and/or DHW	X			X		X	X	X	X	X	X
	Thermal storage to manage refrigeration load peak			X							X	
	Integral refrigeration based on water loop within the refrigeration system		X									
	HVAC&R water loop distribution inside building		X									
Artificial lighting systems	General Retail Lighting (GRL)	X	X	X	X	X	X	X	X	X	X	X
	projector/mirror system	X	X	X	X	X	X			X	X	
	LED wallwasher	X		X	X	X	X	X	X	X	X	X

[CS]=CitySyd; [ME]=Mercado del Val; [GE]=Genova; [BC]=Brent Cross; [KA]=Katané; [DO] = Donauzentrum; [PA]=Pamarys; [ST]= Studlendas; [WS]=Waasland; [GB]= Grand Bazar; [MO]= Modena

The solution sets shall accomplish three specific targets, which are:

- 75% energy consumption reduction (compared to the baseline).
- 7 years payback time (PBT).
- To keep an acceptable Indoor Environment Quality (IEQ) level

1.1 Energy consumption reduction

This target specifies a **75%** of primary **energy consumption** reduction. It is important to consider that the only parameter that can be shown as one unique value is the Primary energy due the homogenized interpretation of the concept of Primary energy.

The following paragraphs clarify the bases for the objectives accomplishment justification. First of all, some definitions are necessary in order to assure the understanding of the following descriptions:

- Useful energy: The energy that finally provides the service (e.g. cooling & heating energy, lighting, refrigeration, etc).
- Final energy: The energy effectively measured in all the energy meters and also published in the energy bills.
- Primary energy: The hypothetical associated amount of energy related to each energy source. In this point, all the different energy sources are homogenized because the units of Primary energy are comparable between them.

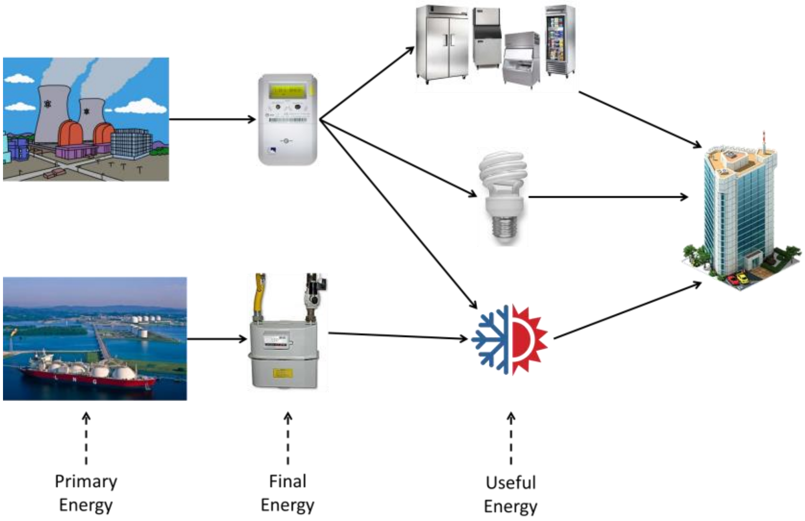


Figure 1-2. Primary, Final and Useful Energy relationship.

The relation between Primary energy and Final energy are the conversion factors officially published in each country. On the other hand, the relation between Useful energy and Final energy are the efficiency of the different equipment involved in the energy transformation.

The following metrics are proposed to justify this objective:

- % reduction of final energy sources (electricity, natural gas, biomass, etc). (indicator that provides useful information to stakeholders)
- % reduction of primary energy (one unique value)

1.2 Payback time

This target specifies a limit of **7 years** on the **payback time**. This objective will be verified using an excel tool, developed within the task T5.1. For the analysis, a payback time calculated with different discounted cash flows is used (from 0% to 8%).

The same generic scenario is applied to the economic analysis of all the reference buildings in order to have comparable results. The assumptions of this generic scenario are reported in Table 1-5.

Table 1-5. Assumptions of the economic analysis.

Boundary conditions	**Value**
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	0-8%
Energy costs	
Electricity buy price annual variation	1.0%/year
Electricity sell price annual variation	1.0%/year
Installation ageing	0.5%/year
Operation costs	
Insurance	0.5%
Taxes	1.0%
Maintenance	1.5%
Miscelaneous supplies	0.2%
Contingency	10% from previous concepts
Annual variation	0.5% each

1.3 Acceptable Indoor Environment Quality level

The comfort is established taking into account the information provided by the owners or energy managers in each shopping mall. They informed us about current temperature setpoints and possible changes on settings, as well as other aspects such as visual comfort and acoustics, in order to take them into account during the solution-sets definition procedure

1.4 Methodology

The methodology followed for the definition of solution-sets is summarized in Figure 1-3.

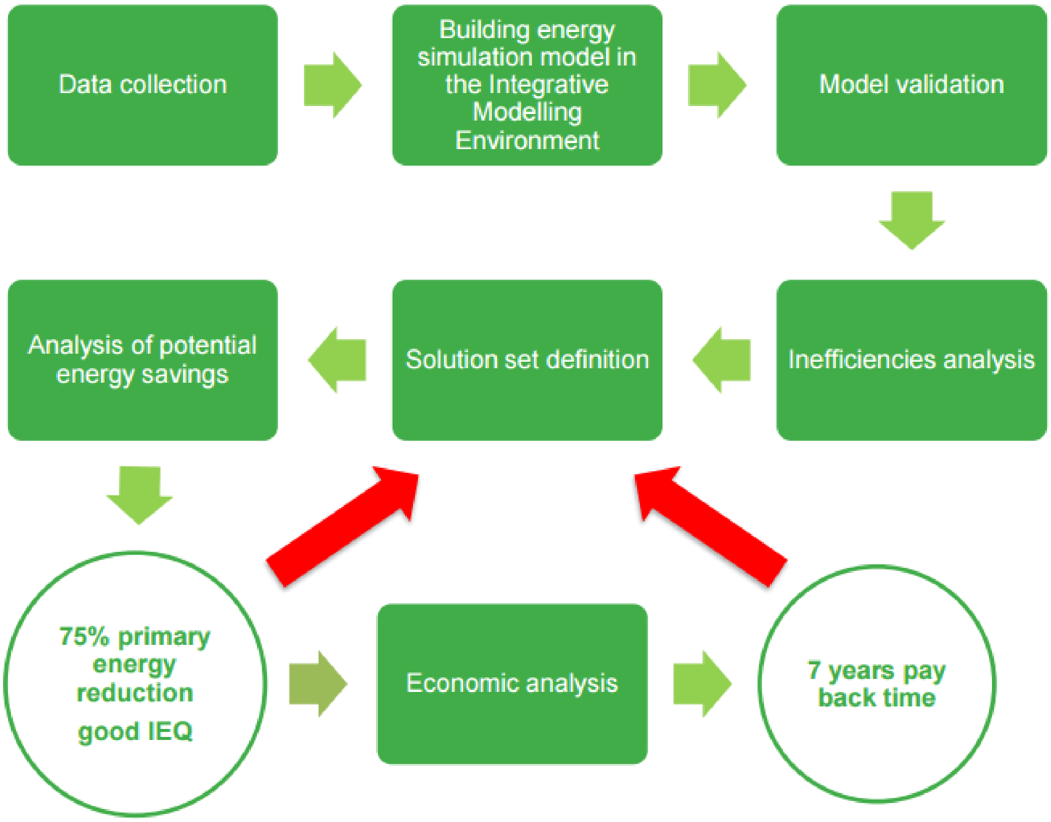


Figure 1-3. Methodology followed for defining solution-sets.

Data collection

Reference shopping centres representatives provided us with data about reference building features, operation modes and measured data to build an energy simulation model. A close contact with representative people (owners/managers) was essential, via mails and telephone interviews when it was necessary. Along the activity, two main workshops were performed. The first one in Wien (October 2014) with a first presentation of the simulation models and a second one in Valladolid (October 2016) with the final definition of the solution-sets identified. Workshops minutes are reported in Annex III.

Building energy model

The building energy simulation models enable us to predict energy consumption and loads on hourly basis, as well as indoor conditions and interactions among solutions, and they can be also used for defining management strategies. The Integrated Modelling Environment (IME) developed within the project (Dipasquale C., 2016) is used to support all the shopping mall retrofitting phases.

The IME, gathering in the same simulation model (i) building (ii) HVAC, refrigeration systems and components (iii) daylighting/shading/lighting (iv) storage technologies (v) RES technologies (vi) natural ventilation and infiltration (vii) non-conventional envelope solutions (vegetation, multi-functional coating and materials, etc.), allows to take into account the interactions among solutions.

Model validation

Reference building models allow to perform qualitative studies on energy saving potential of defined solution sets. Due to the high uncertainty in input assumptions of the model, a model calibration against utility data is necessary for the solution sets analysis to be considered valuable to the building owners.

Several issues prevent us to perform a proper calibration of the reference buildings models:

- Insufficient data resolution: In order to calibrate the model properly and enable the energy savings estimation due to retrofit solutions, at least hourly profiles are needed because they allow to define typical daily consumption profiles.
- Weather data: weather data on specific time period simultaneous to the measured consumption data are needed to perform a model calibration. On site weather stations will be installed in each demo site and we purchased weather data file over a specific time period for each location where the reference buildings are.
- Aggregated data: For most of the reference buildings, measured data about electricity demand are available but they are not broken down into energy uses. Furthermore, it is hard to gather measured data from tenants since each shop is managed according to the franchise network rules.

Table 1-6 reports about the monitored data available for the reference buildings.

Table 1-6. Available monitored data of reference buildings

Reference building	Available monitored data?	Monitoring period	Data frequency	Meter	Data description and notes
CitySyd	Y	2013-2014	hourly[1] 15min[2]	Electricity, district heating[3]	Shared electricity are monitored at two distribution boards, one old and one new (the last only the cooling machines as load). Besides electricity for outdoor lighting is monitored. Tenants have individual meters, but data are not available for other than demo space tenant.
Mercado Del Val	N[4]	-	-	-	
Coop Valbisagno	Y	2013	monthly	Electricity consumption	Data are divided into food refrigeration plants and HVAC-lighting-laboratories-other and refer only to the old supermarket
Brent Cross	N	2014	monthly	Electricity consumption	Electricity and gas monthly bills

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[1] Common areas electricity consumption and district heating

[2] Tenants net cooling and possibly electricity consumption for demospace tenants

[3] 3 meters for shared electricity and district heating consumption. All are connected to EMS web log system. Tenants meters are read manually quarterly, and sub meters of tenants ice water use is read quarterly (probably volumetric+delta T measurement, since meters display kWh).

[4] some bills but for the old building

Reference building	Available monitored data?	Monitoring period	Data frequency	Meter	Data description and notes
Katane	Y	2010-2014	hourly	Electricity consumption	Data are aggregated and represent the electricity consumption of the common areas
Donauzentrum	Y	2011-2013	monthly	Electricity consumption District heating	Disaggregated data about lighting, elevators, HVAC systems and tenants electricity consumption and district heating per building blocks
Pamarys	N	-	-	-	-
Studlendas	Y	2013	monthly	-	only 1 month data
Waasland	Y	2005-2014	monthly	Electricity and gas consumption	Data are aggregated and represent only common areas consumption (bills)
Grand Bazaar	N	-	-	-	-

The model validation procedure 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 (ASHRAE, 2002): 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

$\hat{y}$ = 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. In most of the cases the target output will be the electricity consumption of the whole building or divided into the main building areas such as common areas, shops or others. In some cases, utility data of district heating or gas consumption are also available and they should be included in the validation as well. According to the ASHRAE guideline 14 (ASHRAE, 2002), 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) 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.

More often building owner provide high frequency data only about common areas. At least a total electric demand of shops should be 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.

The utility data provided are mainly aggregated.

Considering the scarce detail level of utility data, there are three ways to improve model validation:

- Operators interviewing (by showing the baseline results and daily consumption profiles to the building owners we could maybe get more information)
- Benchmarking by defining standard percentage of usage in order to break down aggregated data
- Benchmarking by comparing daily profiles with the standard profiles defined in WP2

According to the ASHRAE guideline 14, where on-site measurement of weather is impractical, the source of weather data shall be the nearest available weather station employing measurement techniques equivalent to those defined by the National Oceanic and Atmospheric Administration for “Class A” sites in the United States

We are inquiring Weather Analytics about the possibility to purchase weather data related to the reference buildings location for a specific period.

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 we are developing. 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 the baseline is a proper starting point and represents as close as possible the real building energy behaviour. In this activity, some buildings have been calibrated with yearly bills or monitored data with hourly of monthly resolution thanks to the close collaboration with shopping centres representatives and others could not be validated due to the absence of suitable data. In this last case, standardized input assumptions were used.

Inefficiencies analysis

Once the baseline is finalized, an analysis process starts in order to identify inefficiencies and possibilities for the implementation of new solutions. The inefficiencies identification is supported by:

- An analysis of the baseline model outcomes
- The shopping mall inefficiencies identified within Wp2 (Woods R., 2015)
- The technology repository (Table 1-2 and Table 1-4)
- The information gathered from building owners

For all the shopping centres, the lighting consumption was the main energy consumer and willing to be optimised. From that point, each reference building, depending on their characteristics, studied which point should be improved.

Solution set definition

After the analysis of the inefficiencies, a first solution set definition is chosen in a qualitative way. The measures are integrated looking for and exploiting synergies among HVAC, lighting, refrigeration, energy use as well as for building correlated services (parking, RES harvesting and local energy production etc.).

The energy savings related the each single measure can be barely broken down since the energy used in a shopping centre is dynamic and based on interactions among HVAC equipment and internal/external loads. Complex and often unexpected interactions might occur between systems and various heat transfer and operation modes.

Therefore, we applied the measure stacking analysis method to evaluate the energy saving related to each measure proposed. This analysis method includes changes from previous measures when calculating subsequent measures in order to avoid double-counting energy savings. In this framework, the order in which the measures are evaluated plays an important role.

In order to avoid double-counting energy savings we proceeded by evaluating first measures that affect internal loads and then measures affecting air systems, central heating and cooling plant and heat rejection. The Integrated Modelling Environment allowed us to take into account the interactions among solutions.

In Figure 1-4**Error! Reference source not found.**, an example is shown explaining how it has been followed an energy efficiency measures stacking method.

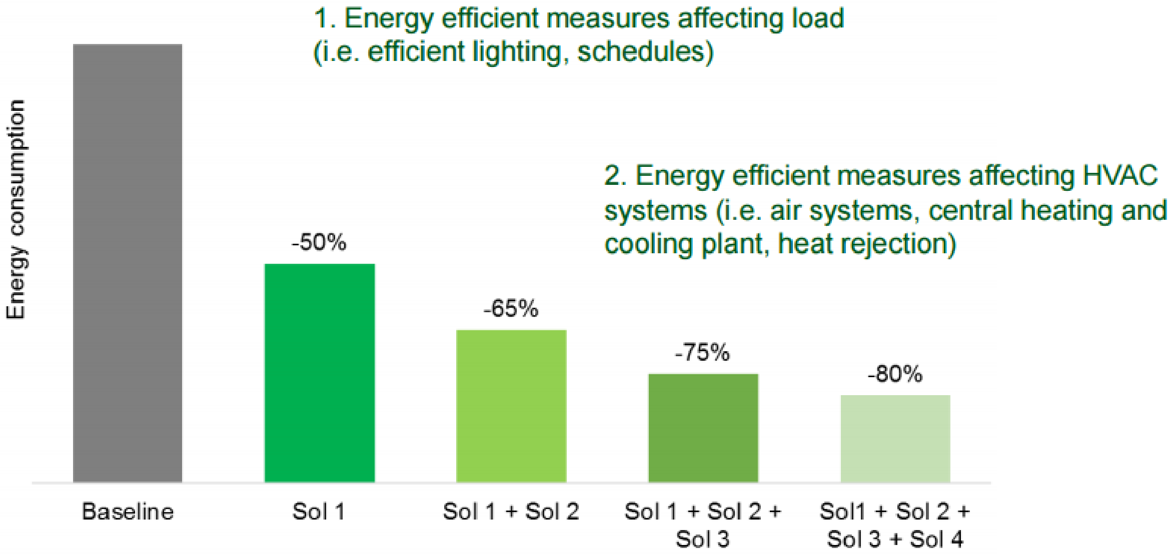


Figure 1-4. Visualization of outputs obtained after stacking method

As represented in Figure 1-4**Error! Reference source not found.**, the reference point is the energy consumption from the baseline (in grey color). In a first step, the energy efficiency measures which affects the internal loads are integrated (lighting, schedules, etc) and in a second stage, energy efficiency measure affecting HVAC systems are implemented (heat recovery, air systems, etc). The study is done by steps, and each step represents the implementation of one solution (energy efficient measure) added to the previous scenario within an integrative procedure (that is, as an example, the introduction of solution 2 means that the simulation will evaluate the baseline model with solution 1 and 2 integrated).

Targets accomplishment

The following step is to proceed with the numerical study using the simulation model and integrating the solutions in order to evaluate the energy savings achieved. As it has been explained, the first objective in this case has been to obtain a 75% of primary energy reduction. After achieving this objective, next step is evaluate from an economic point of view whether the solutions integrated corresponds with a 7-years payback. At this stage, it starts an iterative process with the evaluation of energy savings and economic analysis.

The process ends (and the solution-set is defined) when the combination of solutions and energy efficiency measures reduce the maximum energy consumption with a limit of 7-years of payback time.

1.5 Study of solution-sets in reference buildings

The following chapters refer to each reference building and are structured in the following sections:

- **Technological active-installation check-up**: In order to have a clear and detailed understanding of where and how the different facilities operate to match the building loads, defining which is the current situation of the building in terms of heating/cooling/ventilation & refrigeration equipment.
- **Analysis of energy consumption. Baseline simulation**: Identification and analysis of the current building energy behavior after simulation process (including calibration in those buildings with available data).
- **Selection of suitable solutions**: Taking into account the characteristics of each shopping mall (climate, energy profiles, priorities, inefficiencies, availability of free space or easy installation, etc.) proposal of solutions that could be suitable for each building.
- **Energy savings**: Energy results obtained after simulation analysis implementing the different solutions proposed with the objective of reducing the primary energy as much as possible (facing the 75% reduction as objective).
- **Economic analysis**: to prove the profitability of the investment in energy retrofitting

with the implementation of the different solutions (considering 7 years payback as reference KPI). After this step, the solution-set should be defined.

- **Final considerations**: Summary of results obtained previously assessing foreseen results and the outputs from simulations for the identification of the solution-set.

The different reference buildings studied are listed in Table 1-7 (the first three buildings correspond with the three demo cases) and their location is shown in the map in Figure 1-5.

Table 1-7. Reference buildings list.

Building	Manager	Location
Mercado del Val	Municipality of Valladolid	Valladolid (Spain)
City Syd	Storebrand	Trondheim (Norway)
Coop Canaletto	Coop Estense	Modena (Italy)
Coop Valbisagno	Coop Liguria	Geneva (Italy)
Brent Cross	Hammerson	London (UK)
Katané	Ipercoop Sicilia	Catania (Italy)
Donauzentrum	Unibail Rodamco	Wien (Austria)
Pamarys	Baltisches Haus	Silute (Lithuania)
Studlendas	Baltisches Haus	Klaipeda (Lithuania)
Waasland Shopping Center	Devimo	Sint Niklaas (Belgium)
Grand Bazar	Devimo	Antwerp (Belgium)

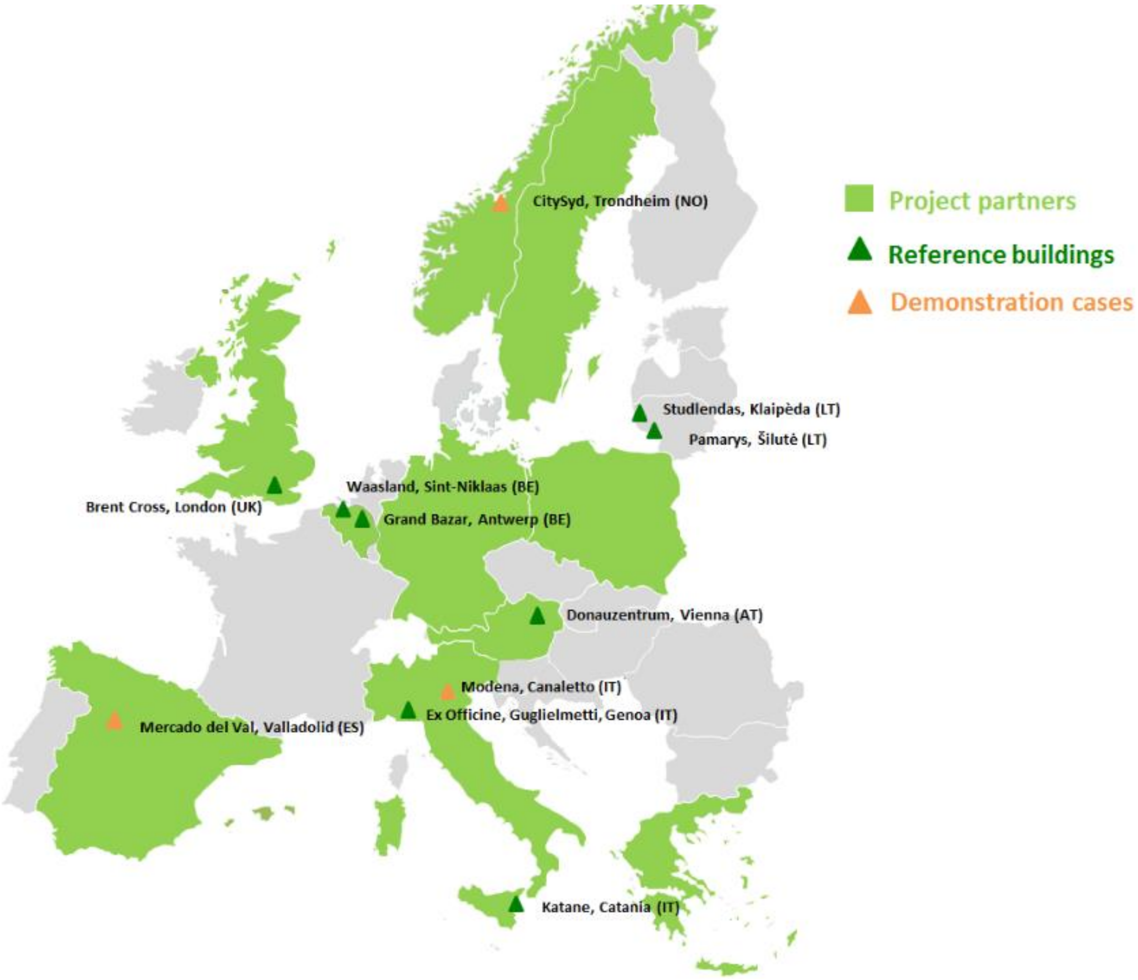


Figure 1-5. Reference shopping centres

2 Mercado del Val (Valladolid - Spain)

“Mercado del Val” (Figure 2-1) 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 modernised. End of 1983 the market reopened with 114 stalls and 2,230 m² in perfect condition.

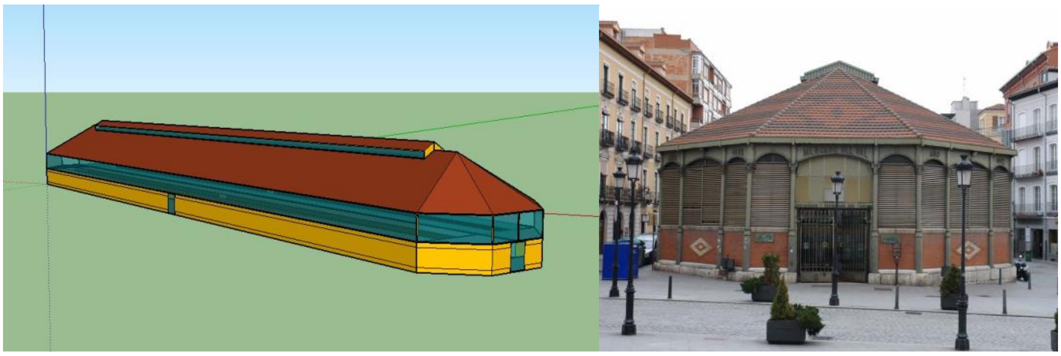


Figure 2-1. Mercado del Val democase: simulation model old building (left), before refurbishment (right).

From 2013, Mercado del Val is fully renovated as part 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 consists of 3 floors distributed in 4,800 m^2:

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

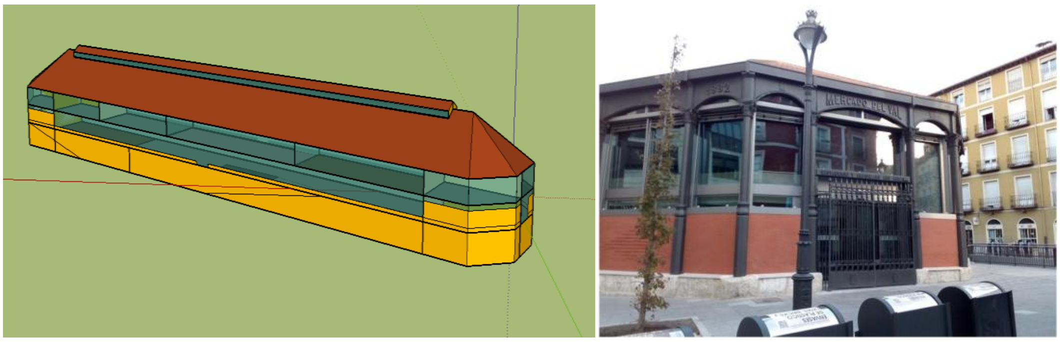


Figure 2-2. Mercado del Val democase: simulation model new building (left), after refurbishment (right).

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.

2.1 Technological active-installation check-up

Old building

Detailed information about energy systems of the building have been collected during the energy audit and reported in Deliverable 6.3 (Antolín J., 2016).

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time.

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.

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

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). The energy model takes into account all the building characteristics and parameters described in the energy audit (Antolín J., 2016).

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.

New building

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time.

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.

2.2 Analysis of energy consumption. Baseline simulation.

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.

New building

At this stage model calibration is not possible as no monitored data is available yet during building operation. Once the building will be operative again and the monitoring will start, model calibration will be possible.

2.3 Selection of suitable solutions

This solution set has been developed for particular buildings as Mercado del Val with some restrictions due to the historical character of the building and other particular considerations as the glazing façade or the use of a geothermal system. Although the glazing façade could be seen at first glance as a no very efficient solution from the energy consumption point of view (glazed in South orientation, for instance) a set of energy efficiency measures improves the energy consumption considerably.

However, although this is a special building, the replication potential is quite high, since the energy efficient measure implemented could be applied to many different shopping centers.

The solution-set finally identified offer 70% of primary energy savings compared to the old building with 6.79 years payback.

The solution set here described is balanced on the specific needs of Mercado del Val demo case building and the climate conditions of Valladolid. A summary of the different solutions studied are shown in Table 2-1 (Annex I shows a more detailed analysis).

Table 2-1. Summary of solutions for Mercado del Val

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Geothermal heat pump**	To supply both heating and cooling there are installed three reversible ground to water geothermal heat pumps, getting temperature from vertical boreholes done on the ground (42 boreholes of 120 m). 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.	There is an increase in the performance of the new heat pumps: Estimated COP and ERR of the old air to water heat pumps 3 and 2.5. Estimated COP and ERR of the new Geothermal heat pumps 3.22 and 5.02.	There is an improvement in the comfort conditions due to the new distribution systems.
2	**Modular climate adaptive multifunctional façade**	Improved glass wall envelope. Daylight exploitation and control: Shading elements in the south façade (lamellas). Natural ventilation system to reduce the cooling needs during summer and reduce energy consumption for ventilation. 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).	More than 75% of heating demand reduction. This reduction includes also the improvement coming from the new structure of the building. More than 80% of cooling reduction. This reduction includes also the improvement coming from the new structure of the building. Mechanical ventilation electricity consumption reduction. Infiltration reduction.	Improve the comfort during the occupied hours. Increasing the air velocity within the indoor environment improves the comfort sensation of customers at high indoor temperatures.
3	**Effective artificial lighting equipment + control strategies**	Installation of more efficient lighting system and different control strategies (Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time) Five different cases have been studied: CommONEnergy project without lighting improvements.	CommONEnergy porject: 55% reduction in lighting consumption. Case 1: 66% reduction in lighting consumption. Case 2: 67% reduction in lighting consumption.	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural

Solutions		Description	Expected energy savings	Expected impact on comfort
		Case 1: Intermediate energy efficient lighting with no control. Case 2: Advanced energy efficient lighting with no control. Case 3: Advanced energy efficient lighting with control for operation hours. Case 4: Advanced energy efficient lighting with control for operation hours and night milieu	Case 3: 73% reduction in lighting consumption. Case 4: 78% reduction in lighting consumption.	environment and it is expected they stay longer in the shopping centre.
4	**RES integration (PV panels + Wind turbine)**	On site RES are a good solutions to produce electricity increasing the self-consumption and self-production and thus reduce the amount extracted from the grid. Good weather conditions but with restrictions coming from the location in the city centre and surrounded by a lot of other buildings and due to their historical character. Surface free of shadows to integrate PV tiles: 865 m² approximately. PV: due to their historical character, is not possible the integration of PV panels. But it would be interesting to study the integration of PV tiles or BIPV in the façade. Photovoltaic generation profile is suitable for the demand profile of the building because the photovoltaic generation peaks normally are going to coincide with the market demand peaks. Small wind turbine: discarded due to the aesthetical reasons and noises.	The yearly simulation performed give us the following energy production estimation: Wind Power: 9,555 kWh/year Photovoltaic: 123,533 kWh/year	-

2.4 Energy savings

The graph in Figure 2-3 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described in paragraph 2.3.

The solution set package analysed leads to a reduction of 70% of electricity consumption. Thanks to the PV and the wind power we can increase to 86%, but as can be seen in Annex I in the Mercado del Val report these RES solutions lead to a ROI above 7 years (out of the scope of the project).

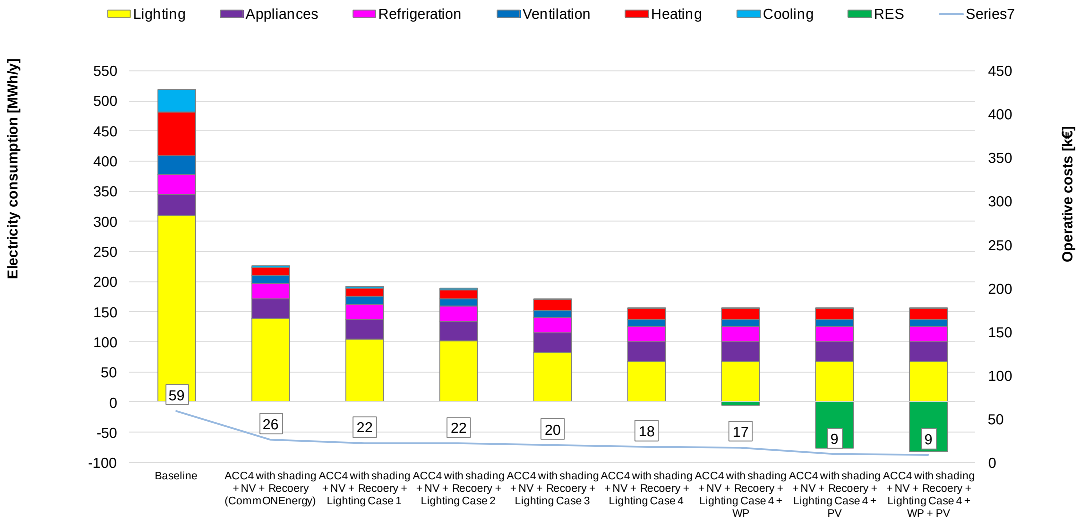


Figure 2-3. Yearly electricity consumption.

The graph in Figure 2-4 shows the actual yearly primary energy consumption of the baseline model and the potential primary energy savings of the energy efficiency measures described in paragraph 2.3, considering a primary energy factor of 2.083 kWh_{pe}/kWh_{el}.

Since the systems are all electric, the percentages of primary energy reduction referred to the baseline are the same as the one estimated for the electric energy savings.

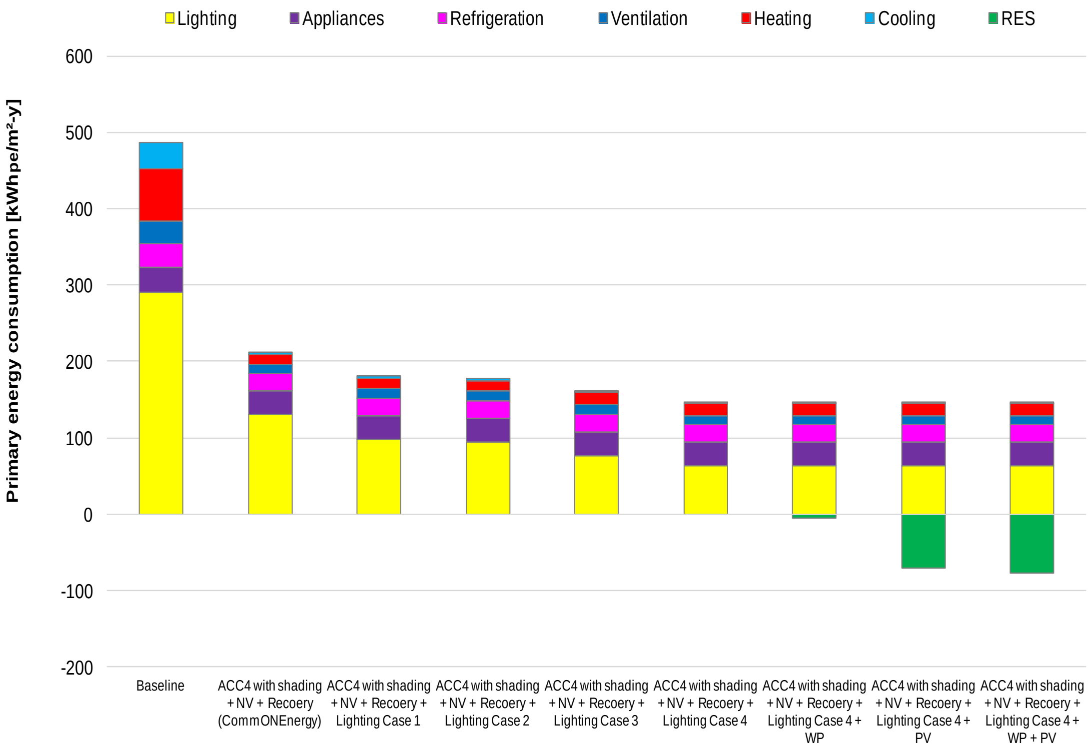


Figure 2-4. Yearly primary energy consumption.

2.5 Economic analysis

For this specific analysis the comparison has been made between the old building and the new building but only taking into account the fresh market itself, this means the ground floor in order to compare a similar surface and type of activity of the building and in this way to have coherent results.

Annex I shows a more detailed analysis, where all the solutions presented has been studied from an economic point of view, rejecting the combinations that are out of the scope.

The solution-set that has a payback time lower than 7 years consist on the installation of the geothermal heat pumps and multifunctional façade together with standard LED lamps.

Table 2-2. Cost-effective solution set for the Mercado del Val democase.

Solutions		measures
1	**Geothermal Heat pump**	Installation of three reversible ground to water geothermal heat pumps.
2	**Multifunctional façade**	Improved glass wall envelope. Shading elements in the south façade (lamellas). Natural ventilation. iBEMS.
3b	**Lighting**	LED dimable, A++ product

As shown in the cash flow diagram in Figure 2-5, this solution-set would have a payback period of 6.86 years.

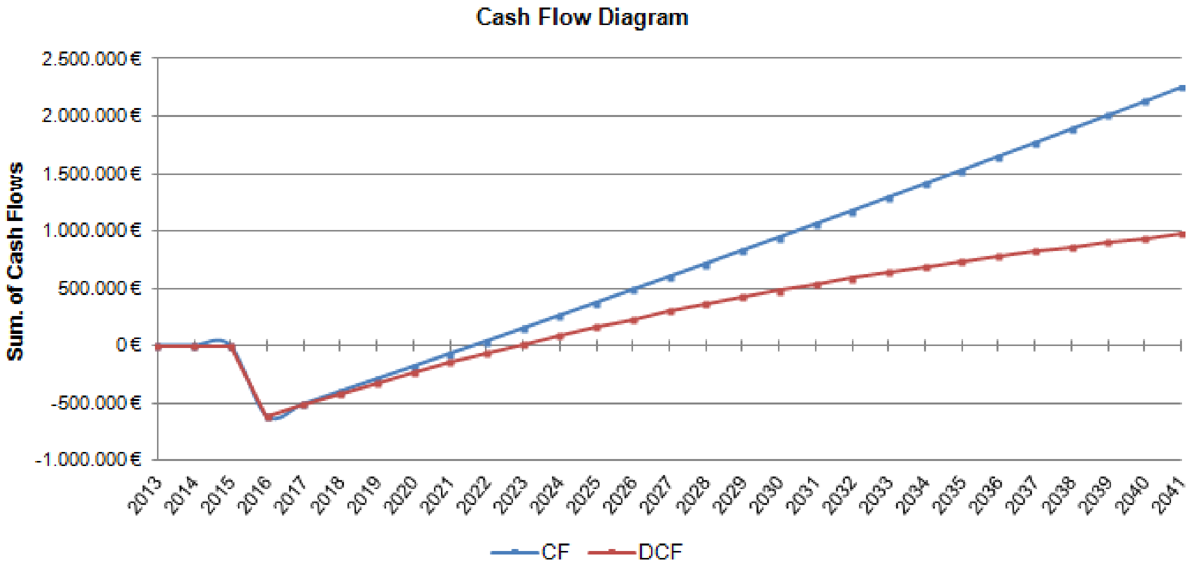


Figure 2-5. Cash flow diagram S1-2-3b.

2.6 Final considerations

Two energy simulation models have been developed, one for the old building (as it was before the renovation) and the other for the new building (which includes the CommONEnergy solutions).

The energy simulation model of the Mercado del Val demo-case has allowed to predict energy consumption and test and quantify potential energy savings with different solutions. For the development of the energy simulation models has been used mainly real information coming from the buildings, but on the other hand, for some aspects in which the information has not been possible to be collected, has been needed to use some assumptions indicated within this document and which need to be cross checked in the case of the new building once real data from the monitoring will be available.

It is important to remark that for the new building at this stage it is necessary to rely on simulation results as no real information from the monitoring is available yet for model calibration. Model calibration will be done once monitored data about building operation are available and included in Deliverable 6.4.Energy savings are calculated in relation to the old building, the baseline case.

After iteratively testing both passive solutions (energy efficiency measures) and active solutions (geothermal heat pumps, artificial lighting and RES), we have obtained the conclusion that have a great potential of improvement above 70%. With the energy efficiency measures here described, it is going to be possible to reduce in a high amount the heating and cooling demand of the building and thus the expenses in electricity for the operation of the HVAC system. With the advanced artificial lighting systems it is going to possible to reduce until 78% of the lighting electrical consumption and thus reduce the electricity bill. With the RES it would be possible to cover part of the electricity demand of the building and in this way to reduce the electricity coming from the grid.. With the geothermal heat pump is possible to cover the heating and cooling demand of the building with renewable energies but also to reduce the electricity consumption in comparison with the old heat pump system due to the increase of performance of the new system.

The first solutions which have been evaluated are the solutions planned as demonstration in the retrofit design. Geothermal heat pumps and the multifunctional façade (**solution 1 and 2**) reduce the primary energy consumption by 56% compared to the old building. These solutions have an investment cost of 557,000 € and the calculated payback time is 6.78 years.

Considering the fact that lighting is responsible for most of the electricity consumption of the market, we second decided to reduce lighting power density **(solution 3)** by replacing old lamps with LED lamps. This solution with an investment of 31,000 €, joined with the previous solutions offered almost 70% of primary energy savings compared to the old building. The implementation of solutions 1, 2 and 3 together would have a payback timeof 6.79 years.

Finally, the introduction of RES will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. Because of the regulation on historic building conservation, it would be possible to install only PV tiles on the roof (**solutions 4**). Firstly, the installation of PV tiles with an estimated investment of around 150,000 €, joined with the previous solutions, would reduce primary energy consumption by 84%. The whole solution set (solution 1 to 4) has a payback time of 7.82 years.

3 City Syd (Trondheim - Norway)

City Syd (Figure 3-1) is a suburban shopping centre, built on the outskirts of Trondheim. Opened in 1987 and covering an area of 28,500 m², it was redeveloped in 2000 and it is now 38,000 m², 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 part of the centre which is taking part in the study is approximately 20,000 m² floor area. The energy retrofit focuses on natural ventilation, iBEMS, as well as natural and artificial lighting.

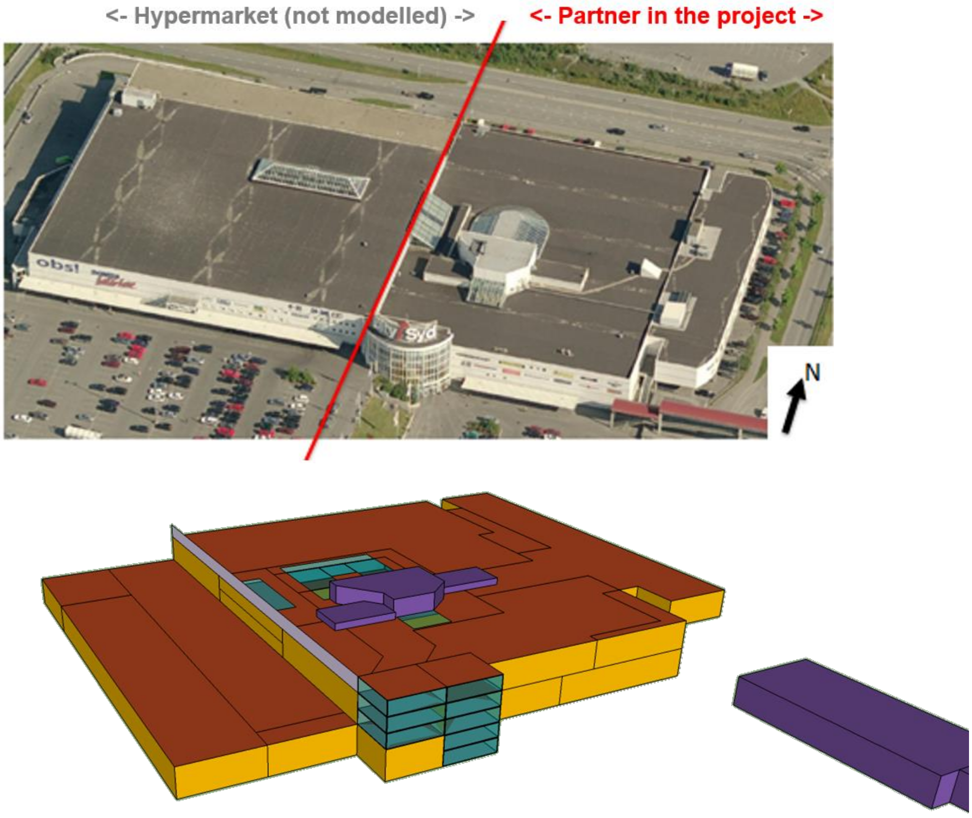


Figure 3-1. CitySyd democase: aerial photo of the shopping centre (top). Simulation model (bottom).

3.1 Technological active-installation check-up

Space heating

The entrance is located to the south towards a large open parking lot. In the entrance area two smaller air curtains have been refitted above the lower entrance doors (ground floor), to limit the use of the larger air curtains (fan capacity 60,000 m³/h) which are located on both floors between the entrance and the galleries (Figure 3-2). This refitted air-curtain run in the heating season, limiting the internal draft exchange between the two entrances within the atrium. One tenant is located within the atrium on the outside of the large air curtains, opposite of the entrance on the ground floor.

District heating is used for the air curtains, as well as a supplement to the Air to Water Heat Pump (AWHP) for heating the ventilation supply air. Additional aero-tempers are installed in cargo entrances and there are snow melting systems in the entrance areas (some are configured to reduce the district heating return temperature). Finally, water is heated for tap water application with district heating (and raised locally by electricity in restaurants, cafes and other consumers requiring higher temperature levels).

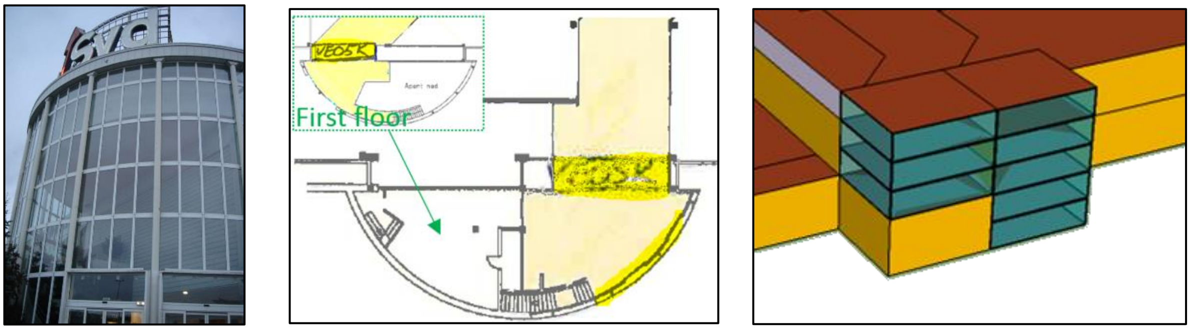


Figure 3-2. Entrance facade (left), plan of the groundfloor outlining the air curtains in yellow (center), and the energy model representation of the multi story atrium entrance area (right).

Ventilation

Ventilation rates are set according to design capacities. Heat recovery efficiency is set according to the type of ventilation unit and performance was spot checked with readings from the building energy management system.

Space cooling

The main cooling machines are dry coolers with a roof mounted unit which run in free cooling mode in the colder season (October to May). Each tenant has their own HVAC system with a cooling plant which is in use (as part of an extension built 15 years ago housing a clothing store). In addition to the cooling machines which provide chill water, the AWHP are switched from heating to cooling mode in the mid-season.

The chill water loop is provided to tenants for space cooling (individual flow meters). Some, but not nearly all tenants are connected with their own cooling baffles and fan coils. Because one tenant use the water for refrigeration purposes, the chill water run 24/7, but this may be changed soon after some in-store renovations.

Natural ventilation

Originally radiant panels for cooling were installed in the common areas, but these are not in use, meaning that common areas are conditioned by ventilation air. Natural ventilation through openable windows in the central atrium skylights helps vent out stale air in the summer. These windows are controlled by a propriety window automation system. This system has a rain sensor, temperature sensors and a wind anemometer which will close the windows when it rains, and when strong wind gusts occur. Complaints of drafts are sometimes an issue, but the system can also be overridden. The opening of the windows happen at several intervals (10% 20 % ... 50 %), but the algorithm that controls this practice is propriety from the manufacturer.

Setpoints

The heating demand of the centre has been calculated by imposing a set point temperature of 20°C in common areas and 18°C in service areas. The cooling demand has been calculated by imposing a set point temperature of 26°C during weekdays (Monday to Saturday) in shop zones. No additional air humidification is considered during the winter time, since this is not the case (see appendix for AHU system diagrams).

3.2 Analysis of energy consumption. Baseline simulation

The district heating demand correlates with outside temperatures, number of visitors in winter (opening and closing of doors on a day to day basis) and possibly wind conditions as the customer entrance is located to the open parking lot towards the south (which correspond with the prevailing wind direction in winter).

An analysis based on hourly data (Figure 3-3, Figure 3-4 and Figure 3-5) show that consumption vary more significantly between opening hours and hours outside of operation in the colder winter months than in the intermediate seasons. Averages include days outside of operation like Sundays. Saturday's opening hours (09-20) differ from weekdays (09-21). In summer district heating is used for tap hot water heating on, which mean that the district heating profile for July directly reflects the tap water demand, but accuracy is limited to the resolution of the data logger values (10 kWh steps). There are some peak hours in winter where draw is more than double of the daily average maximum consumption.

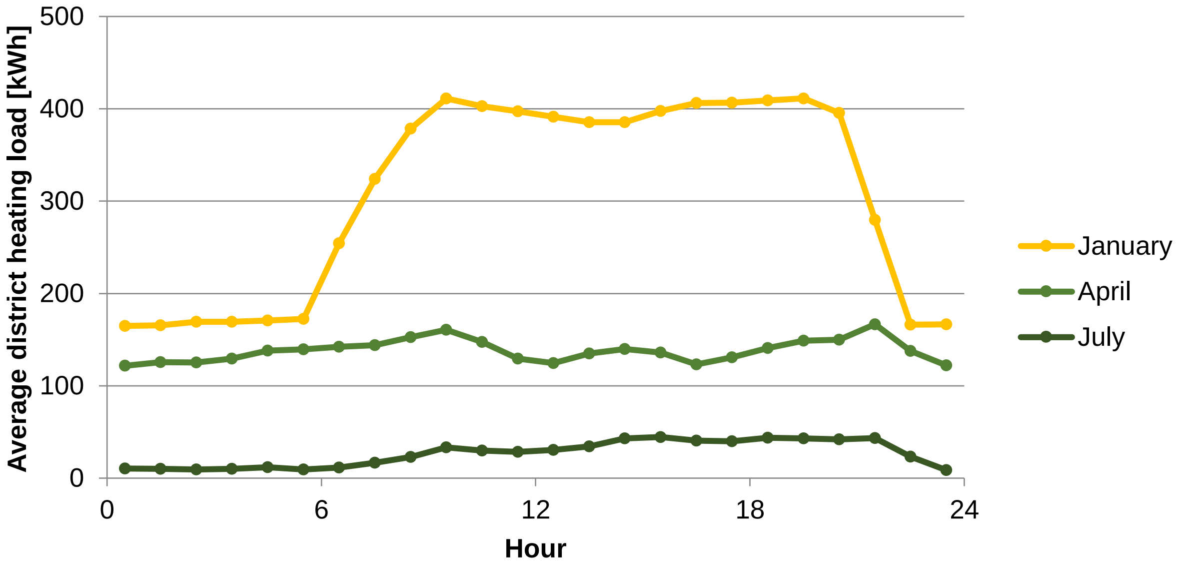


Figure 3-3. Average daily profile of district heating load during January, April and July.

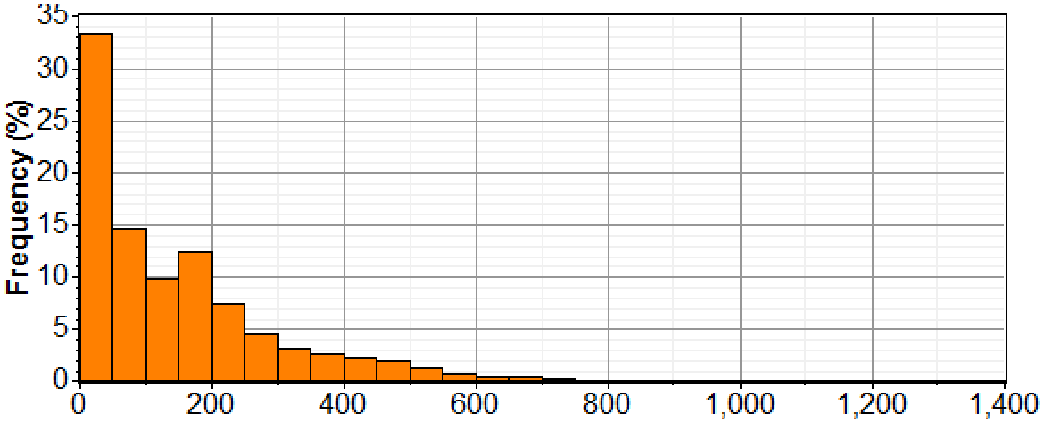


Figure 3-4. Frequency of district heating load based on recoded hourly data for the calibration year.

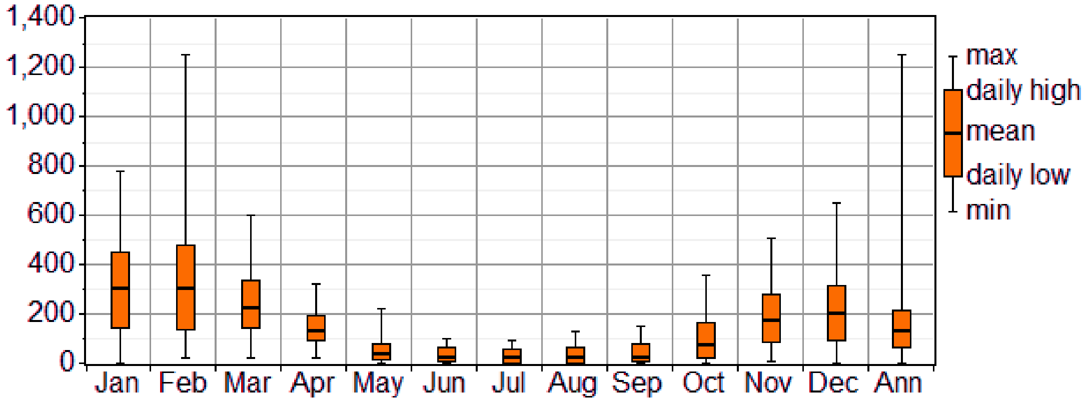


Figure 3-5. Box plots of district heating load based on recoded hourly data for the calibration year.

Shared electricity

Shared electricity (common area lighting, equipment, dual AWHP, cooling machines and central air handling units serving both tenants retail space and common areas) accounts for 1/3 of the total electricity consumption. The electricity demand profiles for each month (Figure 3-6) indicate correlation with season as well as opening hours of the building. Averages include days outside of operation like Sundays. Saturday's opening hours (09-20) differ from weekdays (09-21). An analysis of shared electricity use on a monthly basis show that outside of operation hours there is little variation between minimum recordings and daily low averages (Figure 3-8). This means that electricity draw outside of operation remain on the same level from day to day as well as constant over the year. This observation is supported by the annual frequency distribution curve (Figure 3-7) of shared electricity. More than 40 % of the annual time series fall within this range. Within operation electricity use is 2 to 5 times higher. The highest hourly consumption is reached usually in the opening and closing hours (i.e., 9am) during the winter months and after mid-day during the summer months.

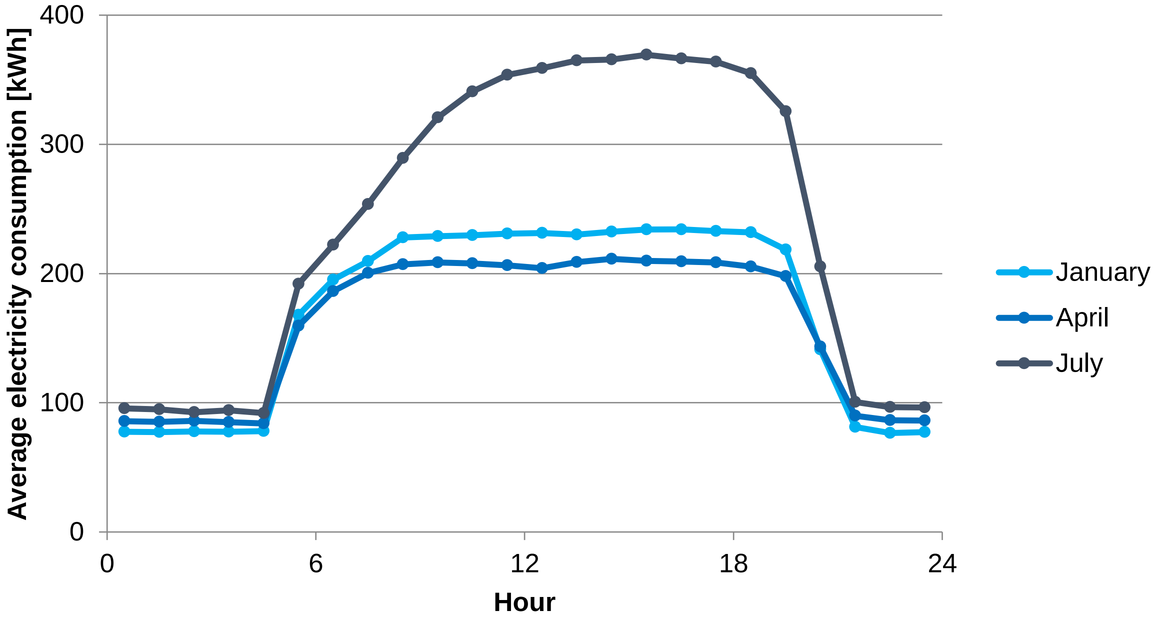


Figure 3-6. Average daily profile of shared electricity use during January, April and July.

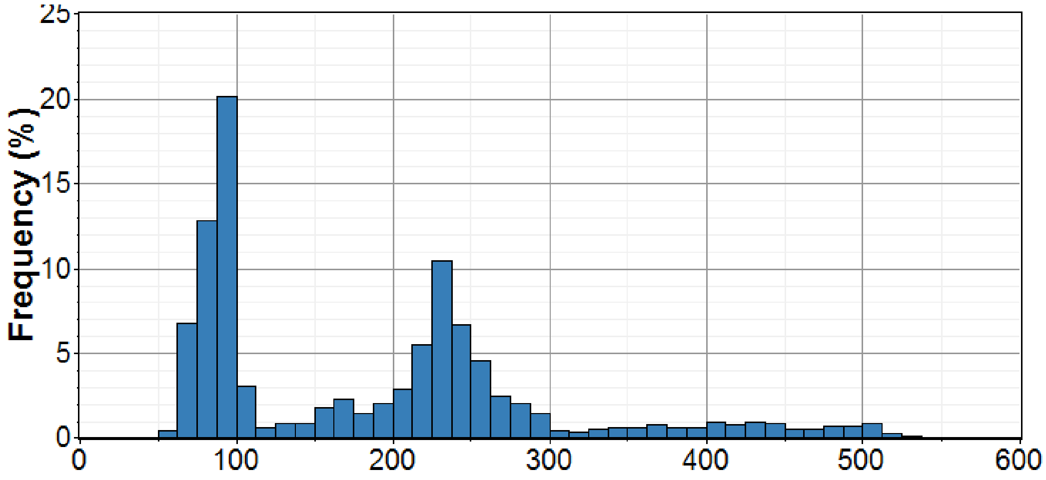


Figure 3-7. Frequency curve of shared electricity use (excluding tenants' electricity and outdoor lighting).

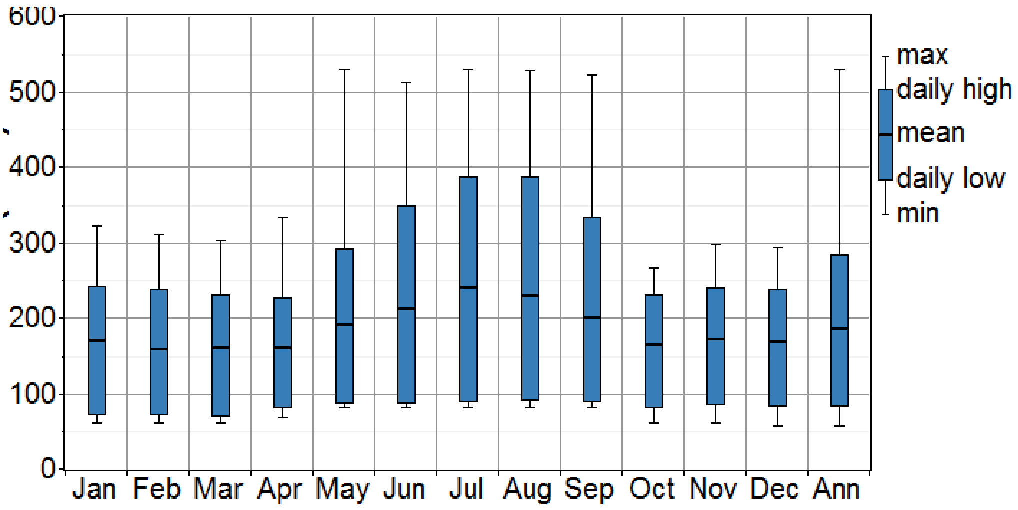


Figure 3-8. Monthly box plots of shared electricity use (excluding tenants' electricity and outdoor lighting).

The remaining share of electricity consumption (tenant's meters) is more constant over the year and largely governed by opening hours, as it is mainly tenants lighting and auxiliary electricity use in retail spaces.

The graphs in Figure 3-9 to Figure 3-11 compare the measured and predicted electricity consumption and district heating load.

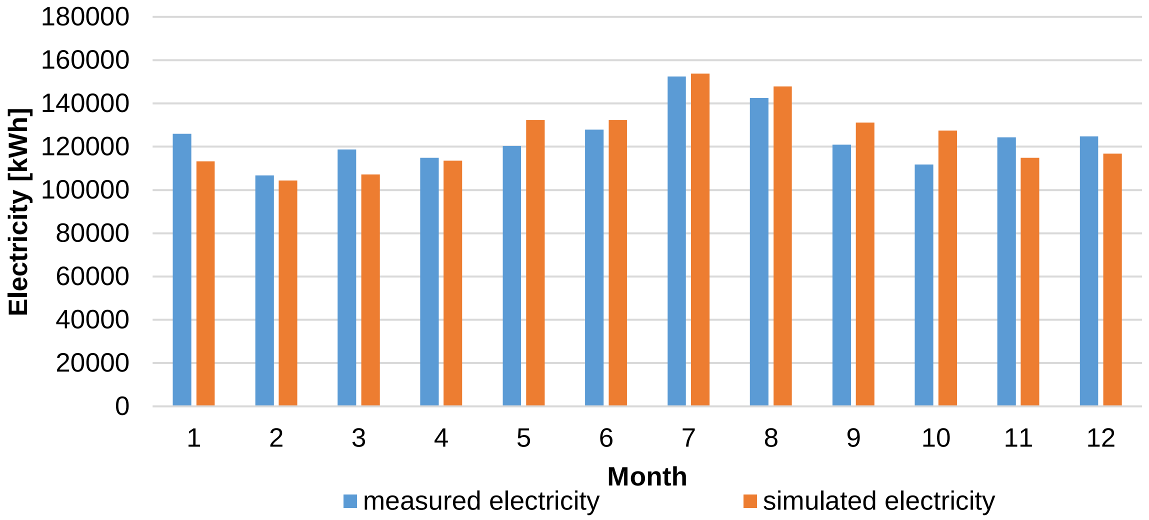


Figure 3-9. Measured and simulated monthly electricity.

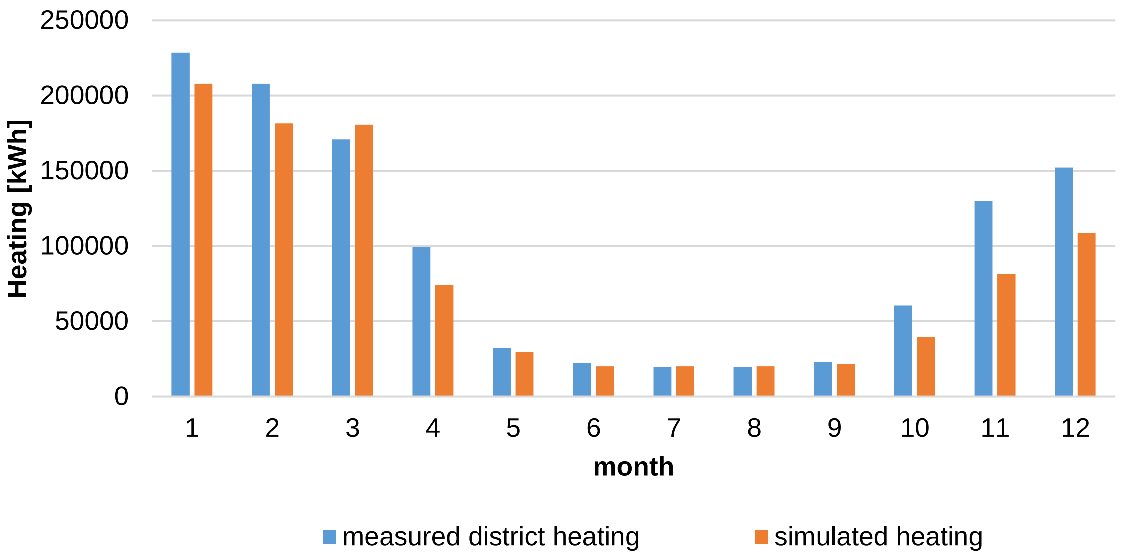


Figure 3-10. Measured and simulated monthly heating.

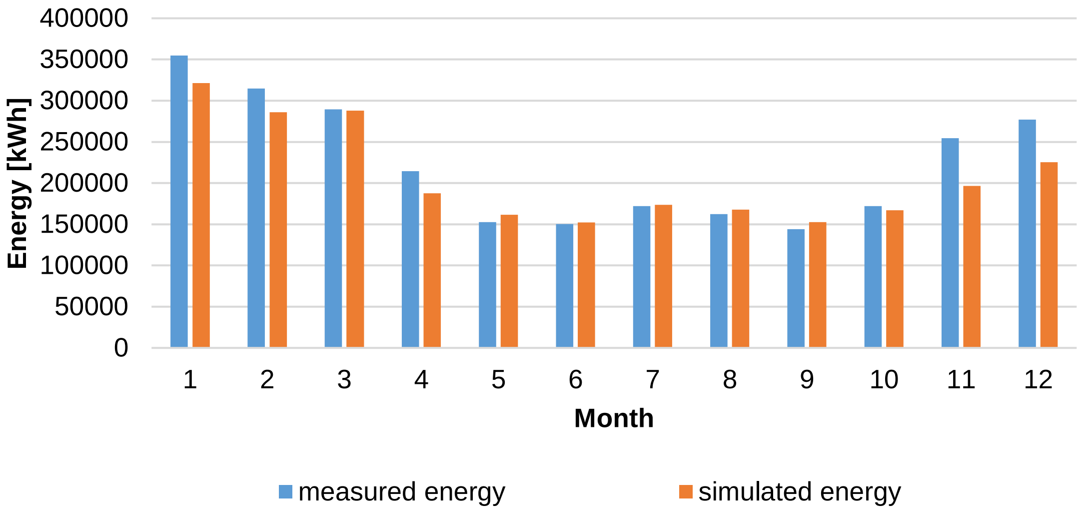


Figure 3-11. Measured and simulated monthly energy.

3.3 Selection of suitable solutions

Table 3-1 reports a description of the solution set proposed for the CitySyd democase. The solution-set has been studied with the objective of satisfying the 7-years payback agreed as KPI for the particular scenario of CitySyd, focused on low cost energy measures. There is a high replication potential for this solution-set for shopping centres in heating dominated climates and with openable windows.

Other solution-set is an extension of the previous one including other energy measures with very good results in energy reduction properties although more expensive, being the improvement in insulation properties and a PV system.

Table 3-1. Description of the solution set studied for CitySyd democase.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Efficient lighting system and controls**	Lighting power density is reduced down to 4.5 W/m² in the common areas and galleries and to 18.1 W/m² in the vending area (shops, midsize stores, food store) because of the installation of LED lamps. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time. The concept of the zonal spatial distribution consisting of a comprehensive set of solutions let us expect savings in energy demand of around 60% against the initial situation. These measures include: Daylight harvesting by 3 light tubes illuminating the center of the sale room with natural light; Application of newly developed LED high lumen retail wallwasher which precisely illuminates merchandise with high efficacy and homogeneity. Glare will be reduced due to very good longitudinal glare control. Beam angle was extended to 120° in order to illuminate not only the merchandise wall but also the area in front to enable optimal examination of goods by customers; Introduction of a evening scenario with warm-white light color of 2700 K und reduced intensity. This lighting scene considers human biorhythm as the indoor room atmosphere is coupled with the natural outdoor lighting environment; Sophisticated control and monitoring strategy that enables highly differentiated space areas.	63% reduction of electricity consumption due to lighting 84% cooling need reduction See appendix for detailed lighting energy analysis	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping centre.
2	**Efficient appliances**	To reduce energy consumption for appliances by exploiting existing systems. Appliances in shopping centres consist of Distribution Transformers IT Equipment (non-data center) Water Treatment/Distribution PCs (Laptops, Desktops, Monitors)	It was assumed that power consumption for appliances is appr. 985 MWh per year (10W/m² in the shops and 1 W/m² during non-operation hours) and 7 W/m² in the	The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.

Solutions		Description	Expected energy savings	Expected impact on comfort
		Cash machines Kitchen Equipment (in restaurants) Refrigerators/Freezers (in supermarkets) Video Displays/Boards Security Systems Vending machine Escalators Elevators Security lighting The appliances will be exchanged in maintenance cycles with high efficiency products.	CMA (during operation and non-operation hours) and can be reduced by energy efficient appliances to 5W/m².(and reduced to 1 W/m² during non-operation hours in shops and common areas). This would result in electricity savings of 389 MWh per year.	
3	**Natural ventilation**	Natural ventilation through openable windows in the central atrium skylights help vent out stale air in the summer. Combining the effect of opened sliding doors and skylight openings can enhance stack ventilation and ventilate/cool the common areas. New entrance door to reduce infiltration.	30% reduction of heating need and 12% reduction of energy needs for ventilation.	Lower ceiling surface temperature improve thermal comfort, especially in the common areas. Improved comfort in restaurant and entrance area due to better control strategy of openings.
4	**Insulation**	Heating energy consumption was reduced by applying 250mm insulation on the roof, changing windows and redesign of delivery entrance area.	20% reduction in heating demand. Actual energy savings can be much higher if other solutions increase heating demand.	-
5	**Photovoltaic plant**	6250 m² PV system (almost) horizontally installed on roof (450kWp). Battery system installed in technical room.	Almost 560MWh electricity production which can be used to reduce electricity demand in the shopping centre. If the PV is combined with a battery energy storage system, advantageous situation are for suppling a dedicated load (e.g. lighting system) or shave the peak (only to smooth the	-

Solutions		Description	Expected energy savings	Expected impact on comfort
			energy profile and not strictly related to the energy prices during the day).	

3.4 Energy savings

The graph in Figure 3-12 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described in par 3.3.

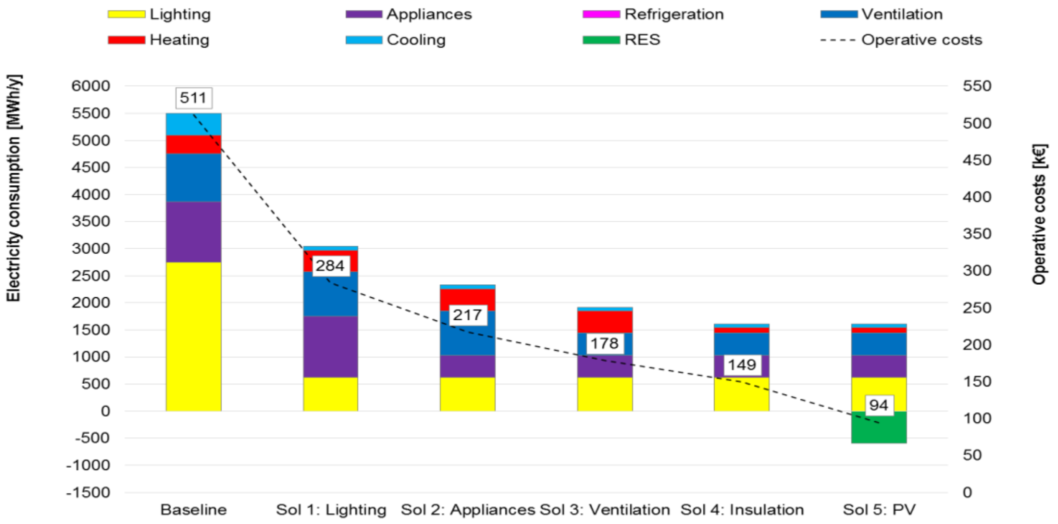


Figure 3-12. Yearly final energy consumption (electricity) and operative costs.

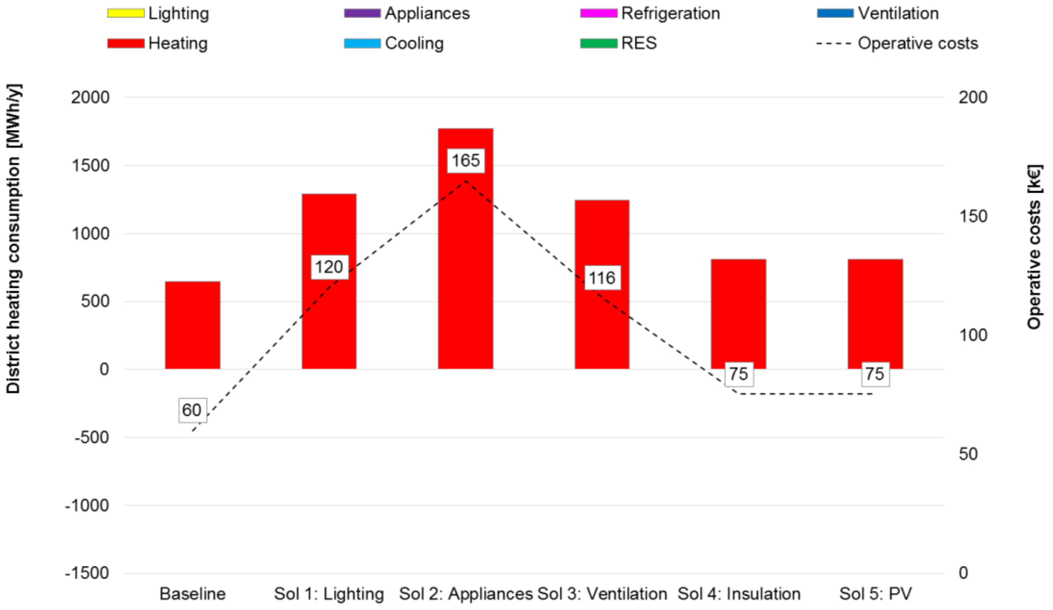


Figure 3-13. Yearly final energy consumption (district heating) and operative costs.

The graph in Figure 3-14 shows the primary energy savings of the solution set.

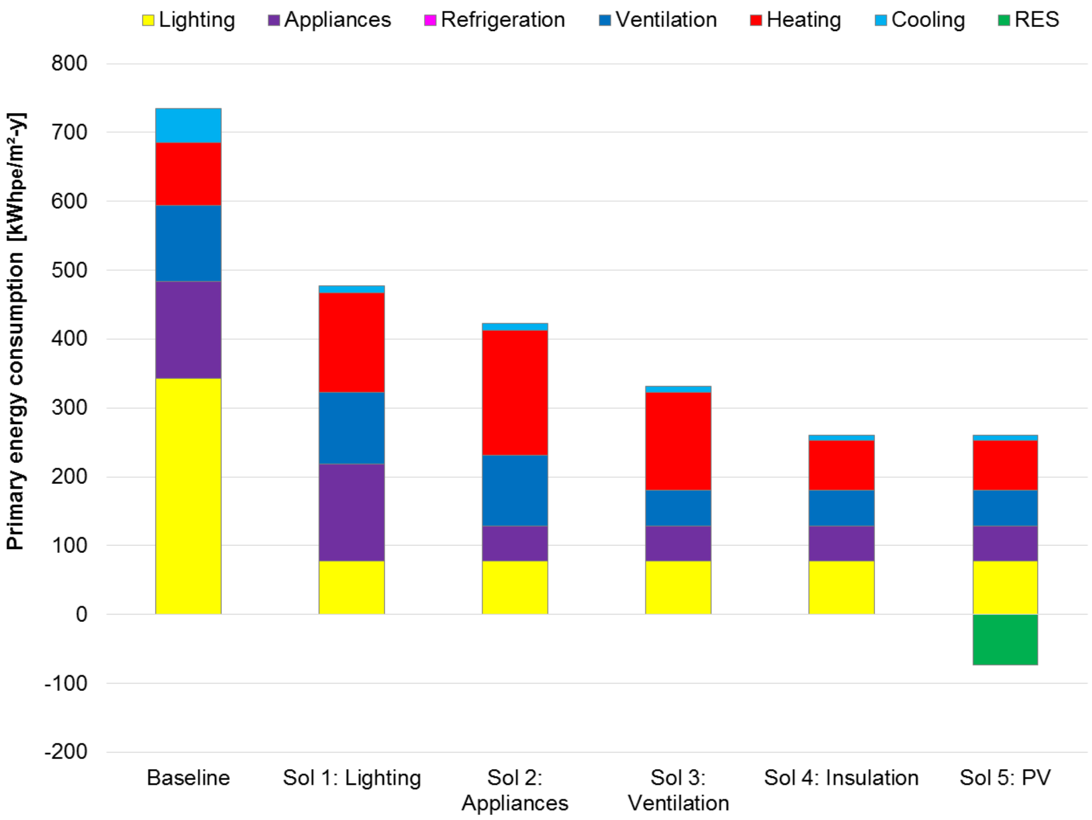


Figure 3-14. Primary energy savings.

3.5 Economic analysis

For the solution set two possible scenarios are presented. First, the economic analysis resulted in a payback period of below or equal to 7 years. This means that economic constraints were identified which resulted in lower primary energy savings.

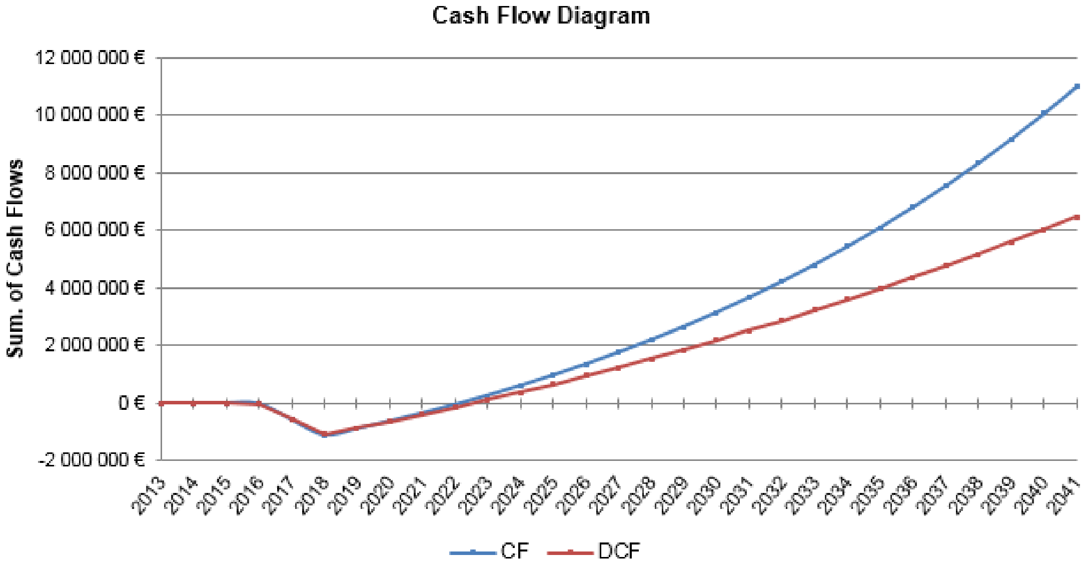


Figure 3-15. Cash flow diagram of solution set.

Table 3-2. Economic evaluation summary.

Solution-set	Individual solutions	Cost of investment [€]	Operation costs savings 1st year [€]	Discounted payback [years]	Primary energy savings [%]	Carbon emission savings [%]
1a	**Lighting** **Appliances** **Ventilation**	1,866,962	292,970	6.6	61	63
1b	**Insulation** **PV system**	3,516,962	353,540	13.7	75	72

3.6 Final considerations

The building energy simulation model was set-up to enable us to predict energy consumption and loads on hourly basis, as well as indoor conditions for each of the reference building. With the help of the model it was possible to define management strategies. The actual consumption data was used, when available, for plausibility check of the simulation results.

It has been tested and quantified the potential energy savings of energy efficiency measures including envelope elements, efficient lighting systems, daylighting systems, ventilative cooling, HVAC+R layouts, renewable energy production and storage systems. Furthermore, we were also analysing the energy efficiency measures from economical point of view since we aim at defining cost-effective and energy efficient solutions for the retrofit of shopping centres.

Thus we fulfilled the following objectives:

- describing the simulation model of the shopping centre City Syd;
- reporting the baseline simulation model results in terms of energy demand and comfort;
- describing the solution set which is going to be proposed for the retrofit.

Two solution sets were developed. We experienced a conflict in reaching all objectives (7 years payback and 75% primary energy savings). Therefore we defined solution sets a and b (a fulfils the payback time restriction, b fulfils the primary energy savings restrictions). For each solution set two possible scenarios are presented. First, the economic analysis resulted in a payback period of below or equal to 7 years. This means that economic constraints were identified which resulted in lower primary energy savings. For those solution sets that resulted in the projected 75% primary energy savings the payback periods were calculated.

Solution set 1a consists of solutions:

- Lighting
- Appliances
- Ventilation

This solution set provides a DPB of 6.57 years. The primary energy savings are 62%.

In addition to the solutions in 1a solution set 1b consists of:

- Insulation
- PV system

as described above. This solution set provides a DPB of 13.66 years. The primary energy savings are 75%.

4 Coop Canaletto (Modena - Italy)

This supermarket of ca. 1200 m² selling area, located in a residential area close to Modena's centre, underwent renovation during the summer 2016, before reopening in September.

The retrofit of the Coop Canaletto demo case is included in an overall neighbourhood requalification with the idea to define a shopping mall including several shops and services both new and existing, for the citizen. The shops/service included in the overall requalification are a bar, a pharmacy, a laundry and some private offices, the existing post office and gymnasium located below the supermarket area.

In the framework of this overall urban requalification, the Coop Canaletto supermarket retrofit is under restyling which includes also energy conservation and energy efficiency measures. The beneficial effects of these measures are presented and analysed in this chapter highlighting the role of each measure in the energy retrofit process.

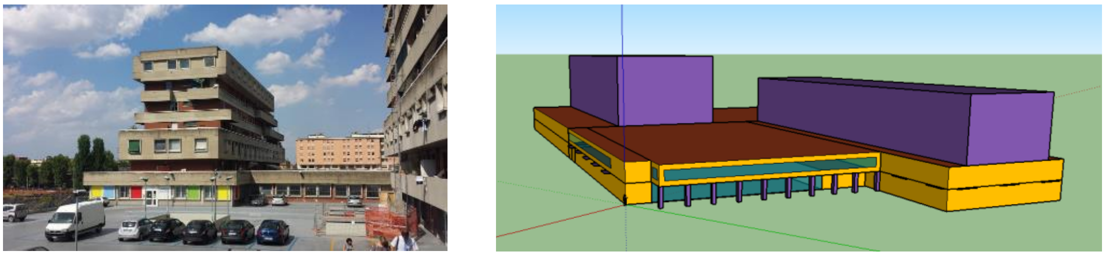


Figure 4-1. Modena Canaletto (left: real building / right: simulation model)

4.1 Technological active-installation check-up

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 the outside temperature goes below 4 °C, the heat pump is switched-off letting the boiler covering the entire heating demand. Otherwise, when the outdoor temperature is higher than 4°C, 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 heating demand of the market has been calculated by imposing a set point temperature of 20°C from 7 am to 8 pm and a setback temperature of 15°C during every day. The cooling demand has been calculated by imposing a set point temperature of 24°C from 7 am to 8 pm. The cooling system is turned off during the night. No additional air humidification is considered during the winter-time.

The refrigeration system consists in both generation and terminal units (cabinets/cold rooms).

There are two separated plants for refrigeration, one for low temperature (LT) and one for medium temperature (MT). Both plants use R404a as refrigerant and air condensers.

Cabinets' characteristics are collected in Annex I.

4.2 Analysis of energy consumption. Baseline simulation.

Figure 4-2 shows the comparison between the monthly electrical consumption measured in 2013 and the one obtained though the baseline simulation, showing each consumption invoice. The simulation model is described in Annex I.

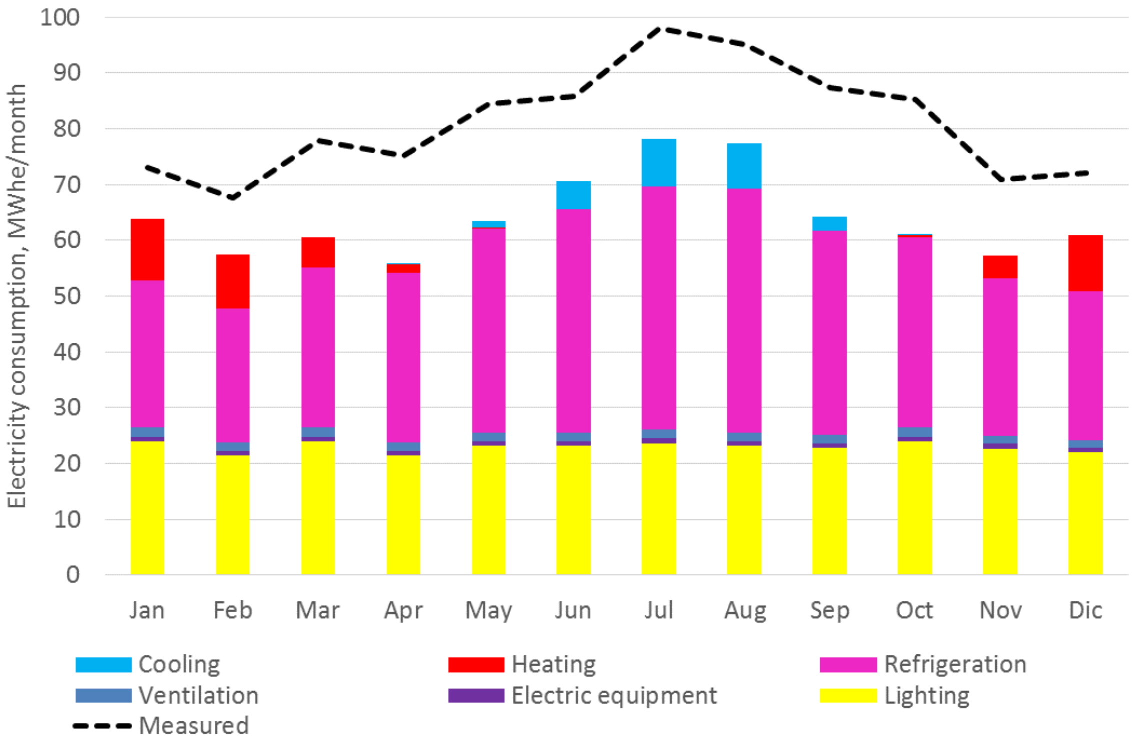


Figure 4-2. Monthly electrical consumption compared with the measured consumption in 2013.

According to model prediction (Figure 4-3), half of the electrical consumption is due to refrigeration (52%), followed by lighting (36%), HVAC (10%) and electrical equipment (1%).

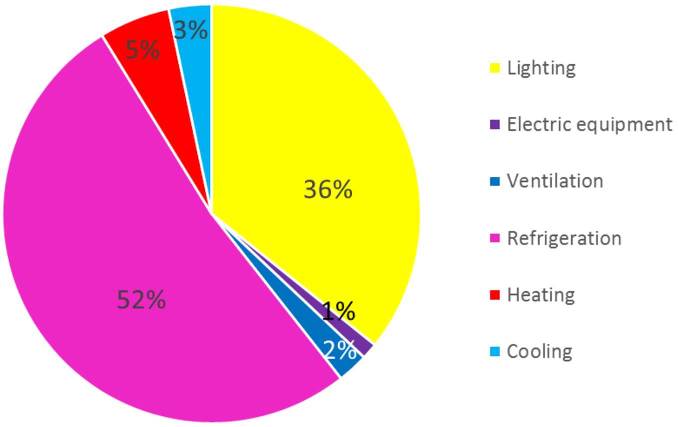


Figure 4-3. Predicted distribution of electrical consumption within a year

The graphs in Figure 4-4 and Figure 4-5 represent the daily profile of electricity consumption in winter and summer, respectively. The higher electrical request on summer days is mainly due to refrigeration because of the higher outdoor temperatures and the cooling demand of the supermarket.

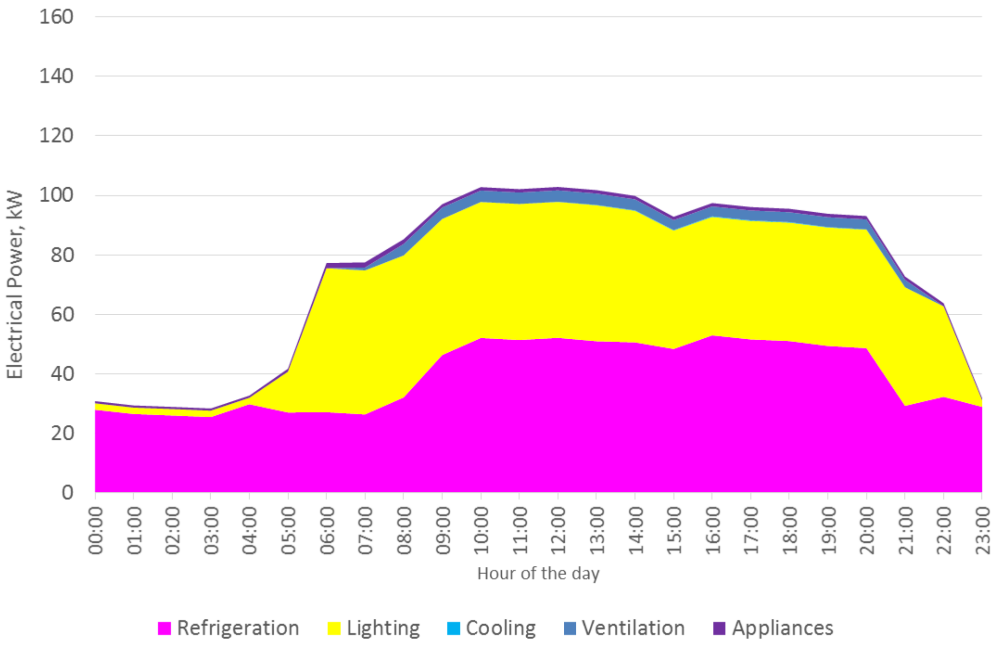


Figure 4-4. Predicted daily profile of electricity consumption of the supermarket in winter.

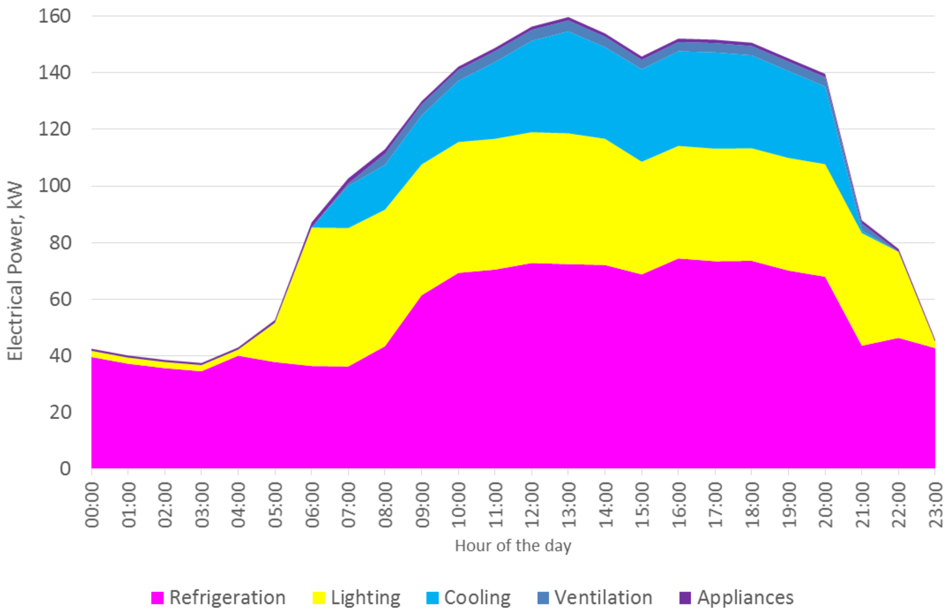


Figure 4-5. Predicted daily profile of electricity consumption of the supermarket in summer.

Total electricity consumption amounts at 781 MWh/y that corresponds to 638 kWh/m²-y considering the conditioned area of 1224 m².

4.3 Selection of suitable solutions

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. 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).

Table 4-1 reports a description of the solution set proposed for the Coop Canaletto demo case.

Table 4-1. Description of the solution set studied for Coop Canaletto demo case.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Efficient lighting system and controls**	Lighting power density is reduced down to 12 W/m² in the entire supermarket because of the installation of LED lamps. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time. Zonal lighting concept reduces ambient lighting, accentuates zones with higher intensity and maintains the perceived brightness impression. Artificial light in food preparation area, where a defined percentage of daylight has to be provided, is controlled dependent of natural light availability with 12 light tubes. Illuminance sensors are also necessary for artificial lighting dimerization.	74% reduction of electricity consumption due to lighting 57% cooling need reduction	Glare is reduced and visual comfort and perception are managed to bring indoor lighting condition closer to outside natural situation (warm-white colour in the evening). Adequate illuminance level in the food preparation zone thanks to the light tubes.
2	**Replacement of refrigeration cabinets**	The solution consists in reducing the refrigeration consumption by replacing old low efficient cabinets with closed new ones (76 m of cabinets) which have better performance and reduced energy consumption	57% reduction of refrigeration consumption 12% reduction in heating demand	More uniform temperature distribution between cabinets corridors and the rest of the supermarket
3	**Building envelope thermal improvement**	External walls are insulated with 7 cm of PIR insulation (applied on the interior side). Total U-value of the wall is 0.26 W/m² K; 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 Ug = 1.01 W/m²K, g-value= 0.28 and aluminium frame with Uf= 0.9 W/m2K.	42% of heating demand reduction 65% of cooling demand reduction	Performant glazed façade allow to restrained discomfort condition close to the perimetral area of the supermarket because of the solar gain coming from outside, especially during summer period.
4	**Reflective coating**	Application of reflective coatings (70-90% reflectivity) on the gym roof area. The coating has also have anti-bacteria, anti-mold and self-cleaning properties.	Energy saving on cooling demand (3%)	Indoor surface roof temperature will be lower or higher depending on the season resulting in a more uniform temperature inside the gym with effect on costumers thermal sensation
5	**Improving HVAC efficiency**	Replacement of the existing generation system (boiler + heat pump) with the heat pump only for the heating and cooling	32% of heating consumption reduction	The free cooling exploitation will allow a reduction of the

Solutions		Description	Expected energy savings	Expected impact on comfort
		production. DHW preparation is provided by an additional heat pump. Installation of a heat recovery section (heat exchanger plus supply and exhaust fan), in the original Air Handling Unit to pre-treat the supplied air. Mechanical free-cooling during daytime and night-time to reduce cooling consumption.	17% of cooling consumption reduction	peak temperature during the day especially during mid-seasons; lower temperature during the first opening hours.
6	**Coupling HVAC and refrigeration**	The central refrigeration unit is replaced with a new one using CO_2 as refrigerated fluid. The performance is comparable to the traditional ones while the environmental impact is highly reduced. The solution aims to integrate refrigeration and HVAC systems. 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. In this solution we test the use of rejected heat from the refrigerated circuit to the space heating controlling the return water temperature at 35 ºC.	Energy savings are expected in the DHW production, as there is continuously an available heat source and also on the heating used by the AHU. Moreover, the decrease of the refrigerant fluid temperature through sub-cooling increases the refrigeration circuit efficiency and, consequently reduces the electricity consumption. Considering only the exchange between the refrigeration circuit and the AHU, the expected savings are: 86% reduction of the heating consumption.	-

4.1 Energy savings

The graph in Figure 4-6 shows the actual yearly final energy consumption of the baseline model and the potential energy savings obtained implementing the retrofit measures described. The graph in Figure 4-7 shows the potential primary energy reduction.

The solution set package analysed leads to a reduction of 62% of electricity/primary energy consumption.

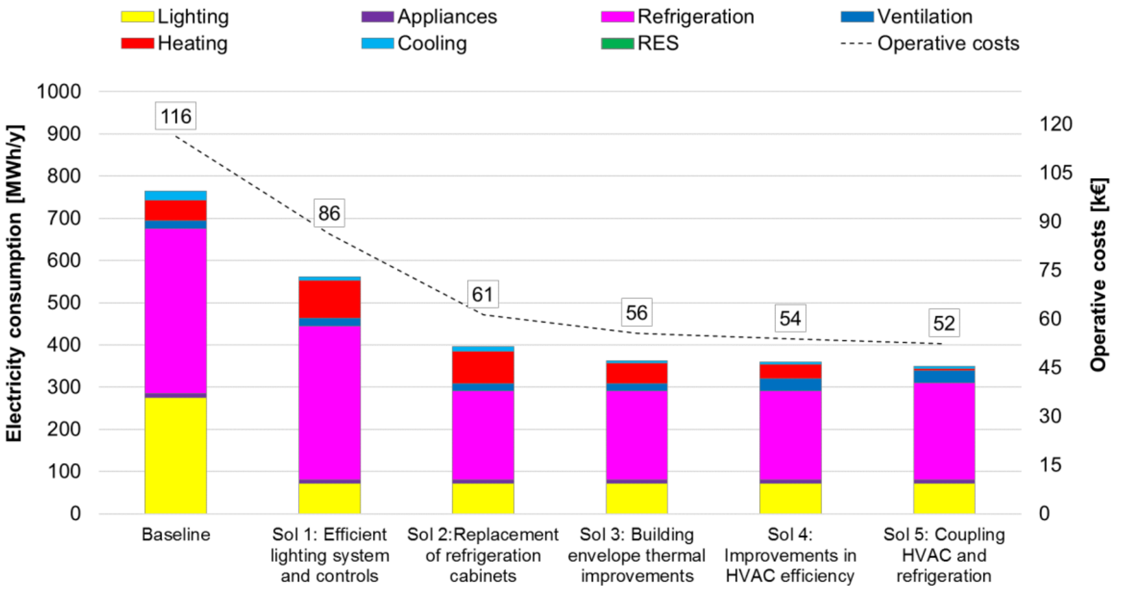


Figure 4-6. Yearly final energy consumption and operative costs in Coop Canaletto supermarket.

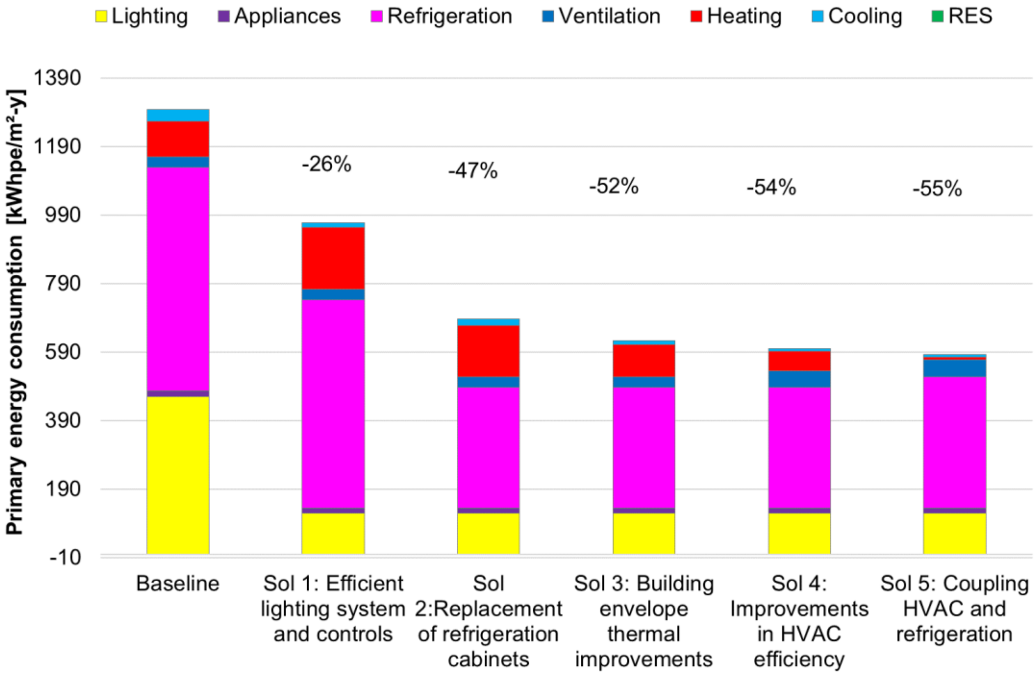


Figure 4-7. Yearly primary energy consumption and operative costs in Coop Canaletto supermarket.

4.2 Economic analysis

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 607,000 €, most of which is due to the refrigeration plant. Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 501,000 €/year.

The results of the cash inflows and outflows for the whole solution set over the 25 years period studied are shown in Figure 4-8. The estimated Pay Back Time is expected to be between **7.3 (discount factor 0%) and 11 years (discount factor 8%)** depending on the discount factor which can be applied to the investment.

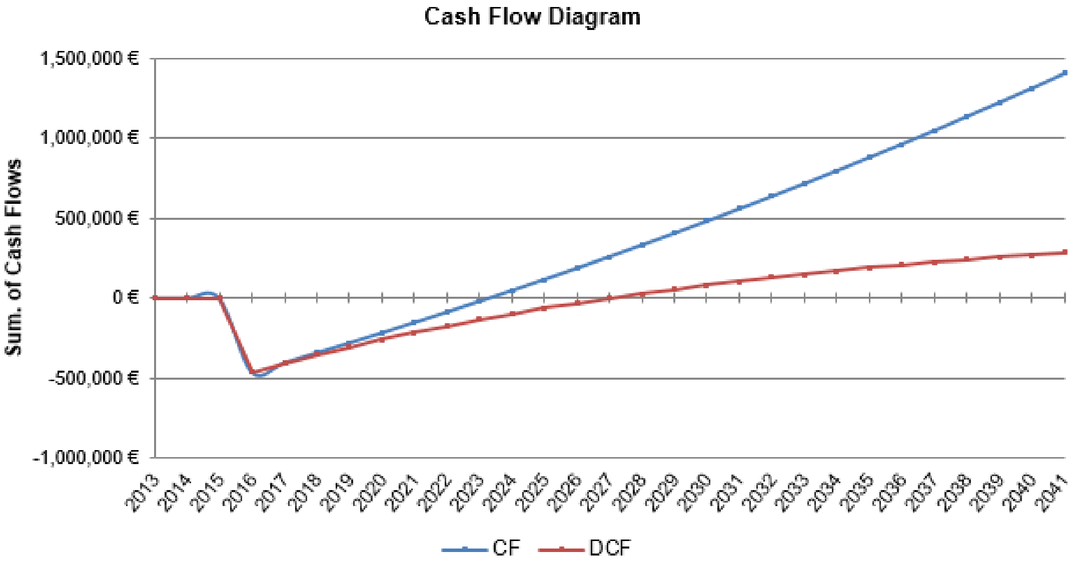


Figure 4-8. Cash flow diagram

4.3 Final considerations

The solution set reflects the specific needs of Coop Canaletto demo case, a small size supermarket which is planned to be completely restyled.

The solution-set proposed includes:

- Solution 1: Efficient lighting system and controls
- Solution 2: Replacement of refrigeration cabinets
- Solution 3: Building envelope thermal improvement
- Solution 4: Reflective coatings
- Solution 5: Improving HVAC efficiency
- Solution 6: Coupling of HVAC and refrigeration system

The results highlighted how improvements in the refrigeration efficiency both from generation side (CO_2 transcritical system) and terminal units (closed cabinets) are essential measures for upgrading the overall energy efficiency of the supermarket opening the possibility of an HVAC – refrigeration coupling. Despite the significant investment costs of around **606,980 €** (incl. tax), the solution set is cost-effective.

The proposed solution set package in fact, can lead to an overall reduction of **62%** of electricity consumption. Considering an average cost of electricity of **0.15 €/kWh**, the energy savings due to energy conservation and efficiency measures from solution 1 up to solution 6 are expected to be **76,518 €** in the first year of operation after retrofit.

The estimated Pay Back Time of the solution set is expected to be between **7.3 (discount factor 0%) and 11 years (discount factor 8%)** depending on the discount factor which can be applied to the investment**.**

5 Coop Valbisagno (Genua - Italy)

Coop Valbisagno, situated in a populous neighbourhood close to the Valbisagno river, is an existing shopping mall including a Coop supermarket of about 4000 m² selling area that will be renovated.

Next to the mall, industrial buildings (Officine Guglielmetti) will be demolished and partially rebuilt with a connection to the existing shopping mall. At the end of the refurbishment, there will be a modern shopping mall, a grocery and other medium and small shops. The intervention will also include a hotel with 150 rooms, parking lots (below and above ground) and a plaza for the neighbourhood citizens. The area will go through a major urban redevelopment: the built volume will be larger than the actual and the area will be recovered and included in the urban use.

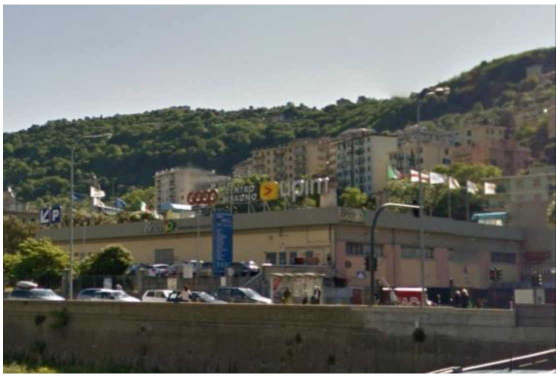


Figure 5-1. Actual Coop supermarket in Val Bisagno. Source: Google Map street view

Figure 5-2. Render of the retrofit project with enlargement on ex Officine Guglielmetti area. Source: INRES, 2014.

The underground floor is assigned to the parking lot and warehouses; the southern zone is used as entrance for the hotel. Commercial floor involves two common areas running on the main axes of the building (north to south and east to west), surrounded by shops and two media store on the south wing and northern wing. A big Coop food store (6350 m²) will be located next to the western glazed hallway, on the south-eastern corner of the store. The project proposal designed from the architects involves a big glazed atrium located on the western facade, with an elevator placed on the southern side that will guarantee access to the open green park on the roof as well as the commercial gallery and the underground parking lot.

The climate is cooling dominated. The centre is opened from 8:30 until 19:30, seven days per week.

Since this renovation project will enlarge the building volume for more than three times, we defined as baseline model the building as designed.

The energy savings potential of the proposed solution will be calculated according to the energy performance predicted by this reference model.

5.1 Technological active-installation check-up

Due to the complexity of the building and the number of circuits, only the HVAC systems for the food-store, common areas and mid-stores have been modelled and simulated. In these zones, the HVAC system has been modelled with all its components. The other zones have been kept with the ideal loads calculation that uses unlimited power, able to guarantee the indoor temperature within heating and cooling set-point all the time.

Despite the original plan of having rooftop machines, the reported results refer to a system with water-to-water heat pumps as it has been studied the water loop solution. In light of this, the implemented system foresees three water-to-water heat pumps, one for each zone typology (food-store, common areas, mid-stores) connected in a water-loop. The water temperature in the loop is maintained between a certain range (10-25°C) by a dry cooler working in winter and summer mode.

Each zone typology is conditioned by an AHU fed by one of the three heat pumps. The AHU is composed by a heat recovery, cooling and heating coils and recirculation valve. Then the conditioned air is split into each thermal zone.

The units recover part of the exhaust air and mix it with outdoor air: the portion of recirculated air is regulated for guaranteeing the minimum air changes rate. Full recirculation mode is set in the first opening hours until the set-point indoor temperature is reached. The system works at minimum air changes rate when free-cooling is activated and with increased air flow when it is conditioning.

For the shops' air conditioning, we considered the following efficiencies to estimate the electricity consumption: EER = 3; COP = 3.5.

The 70% of the maximum damper opening is set as the minimum hygienic air changes. The ventilation flow rate is calculated in order to be able to cover the maximum building load.

During the non-occupied time the fan is switched off. Pumps, fans and heat pumps are modelled based on generic components' datasheet as the specific models were not available.

Refrigerated cabinets and cold rooms typologies and quantities are based on the designed ones. The refrigeration is based on a cascade system with CO_2 as refrigerant for the direct expansion LT (Low Temperature) equipment, and R134a as refrigerant for the MT (Medium Temperature) portion of the system.

5.2 Analysis of energy consumption. Baseline simulation.

The graph in Figure 5-3 represents the electricity consumption divided by zone function. The mid-size stores (MDS) have the highest electricity consumption due to the high lighting power density and, consequently, high cooling demands. According to our model predictions, the most affecting energy use is due to lighting (51%) followed by other electric equipment (16%), ventilation (12%), refrigeration (7%), cooling (9%) and heating (4%).

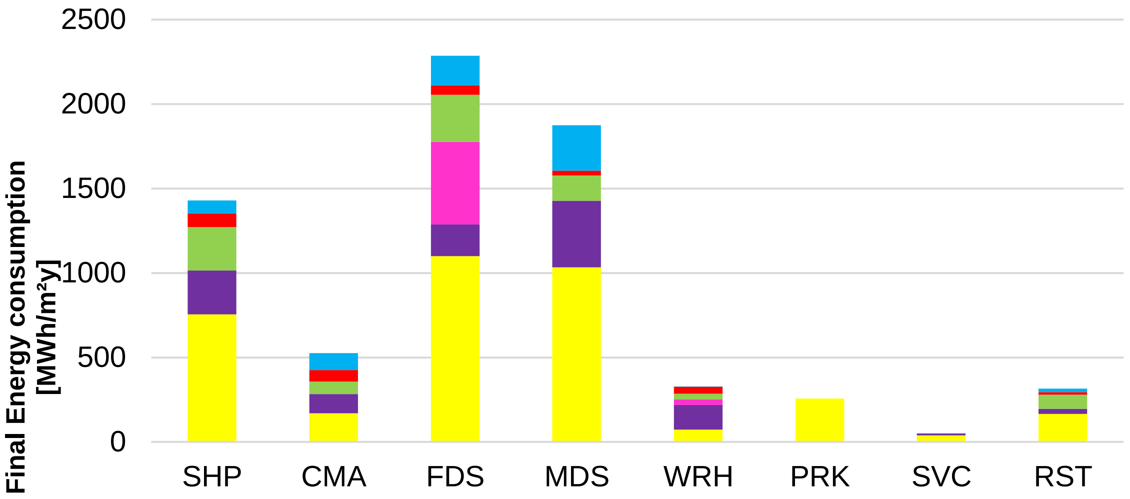


Figure 5-3. Electricity consumption for each group of zones: Common Areas (CMA), Shops (SHP), Midsize store (MDS), Food store (FDS), Warehouse (WRH), Parking (PRK), Services (SVC) and Restaurants (RST).

Total electricity consumption amounts at around 7070 MWh/y which corresponds to 290 kWh/m²-y considering the conditioned area of 24’349 m².

5.3 Selection of suitable solutions

Considering that in Coop Valbisagno both common areas and food store are owned and managed by Coop while shops and midsize stores are leased, the proposed solution set mainly focuses on common areas and food store. Since the shopping centre is under a major renovation process which is still in the planning phase, also interventions on HVAC system and cascade systems can be investigated. Table 5-1 reports a description of the solution set proposed for the Coop Valbisagno reference building.

Table 5-1. Description of the solution set studied for Coop Valbisagno reference building.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Efficient lighting system and controls**	Lighting power density is reduced down to 4.5 W/m² in the common areas and galleries and to 18.1 W/m² in the vending area (shops, midsize stores, food store) because of the installation of LED lamps. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.	50% reduction of electricity consumption due to lighting 25% cooling need reduction	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall.
2	**Refrigeration – CO2**	The use of R744 (CO2) is a leading option for environmental reasons and, thanks to the last technology developments, it is going to be as efficient as the baseline system. Refrigeration with CO2 uses a “natural refrigerant” whose physical properties require special handling. The system pressures are much higher than in conventional systems, but all the components are designed accordingly. Good experience has been gained especially in the coldest climates, but thanks to additional devices, it is promising in the warmer climates too.	In mild climates, the use of transcritical technologies with respect to the traditional ones does not bring wide savings. If an auxiliary compressor is activated, refrigeration with CO2 can have comparable consumption as the traditional ones or even slightly lower. The advantage of this technology is mainly in terms of environment aspects. The new norms in the refrigerating fluids are moving on the direction of CO2 applications	-
3	**Heat pumps water loop**	A water loop acts as source for a number of electric reversible heat pumps which provide climate control on the various thermal zones. Heat recovery is performed collecting heat from the condenser/gas cooler of the refrigeration system in the cold season and transferred to the heat pumps water loop in order to maintain a certain temperature.	Reduction of heat pumps and auxiliary heater electricity consumption in the cold season. Although in the analysed case the heating season is not predominant,	-

Solutions		Description	Expected energy savings	Expected impact on comfort
			the savings on the heating consumption amount to 12%. Cases with longer heating periods or contemporaneity of different loads can expect higher savings.	
4	**Natural ventilation**	Natural ventilation through openable windows in the atrium skylights and in the west facade help vent out stale air in the summer. Combining the effect of opened sliding doors and skylight openings can enhance stack ventilation and ventilate/cool the common areas. The connection of opening control to the iBEMS and the integration of inverters automated by the iBEMS would allow to switch off the mechanical ventilation in the common areas when natural ventilation is activated and to introduce a more sophisticated control strategy.	Electricity consumption due to cooling and ventilation reduced by 20%	Increasing the air velocity within the indoor environment improves the comfort sensation of customers at high indoor temperatures.
5	**Photovoltaic plant**	300 kWp PV plant is installed on the parking canopies on roof parking lots to decrease the energy imported from the grid and the CO_2 emissions by generating and self-consuming renewable energy	The yearly simulation performed using consumption data from common areas and food store, gave the results of around 19% of self-production and 100% of self-consumption.	The PV installation will create shaded parking lots, which are preferred from customers especially during the summer period. Lower ceiling surface temperature improves thermal comfort, especially in the offices on the roof.

5.4 Energy savings

The graphs in Figure 5-4 and Figure 5-5 show the actual yearly final energy and primary energy consumption of the common areas and food store in the baseline model and the potential energy savings of the energy efficiency measures described in par.5.3.

The solution set package analysed leads to a reduction of 40% of electricity consumption compared to the baseline case, which corresponds to the renovation project. Up to 26% of energy savings can be achieved by passive and active solutions. Thanks to the PV plant we can have up to 19% of self-production and 100% of self-consumption.

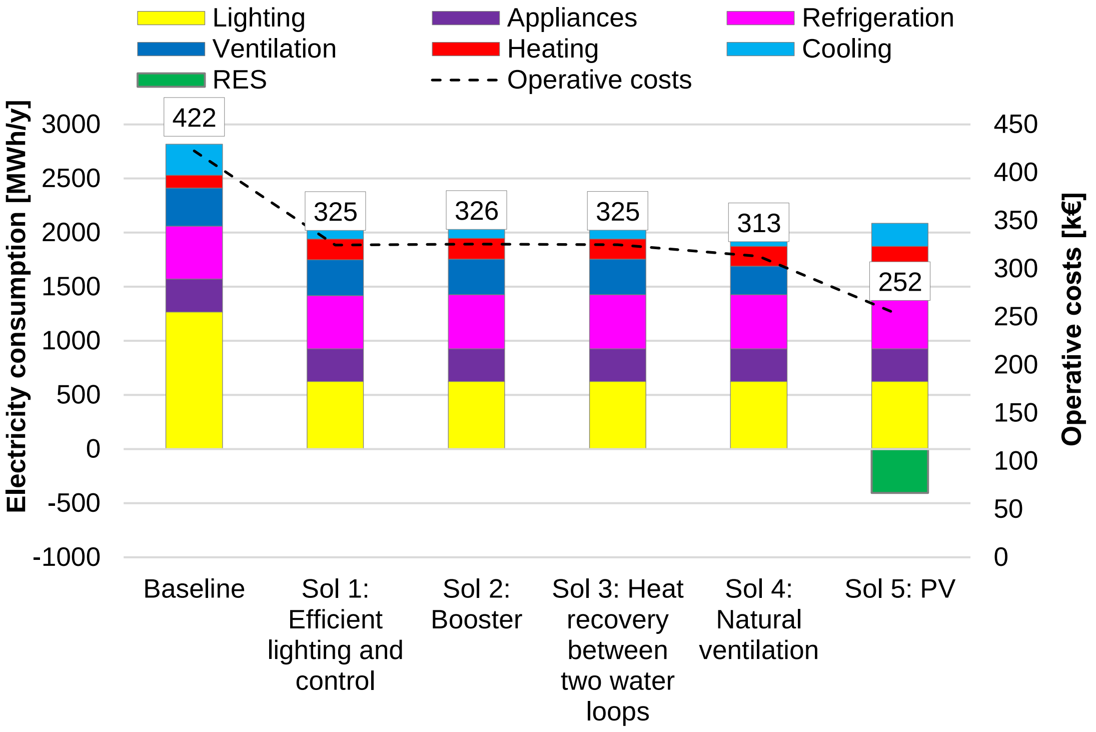


Figure 5-4. Yearly final energy consumption and operative costs in common areas and food store.

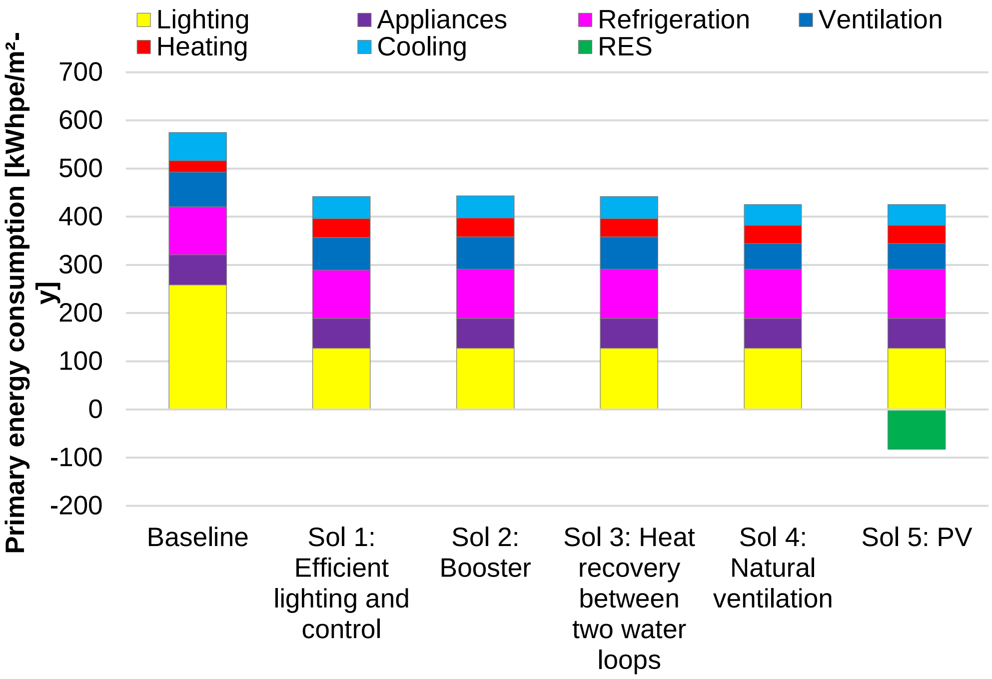


Figure 5-5. Primary energy consumption in common areas and food store.

5.5 Economic analysis

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 1 million €, most of which is due to the PV plant. The total cost of investment of energy conservation and efficiency measures only is estimated at around 526,315 € (incl. tax).

Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 170,000 €/year and the revenues due to the sale of electricity to the grid from the PV plant are estimated as 200 €/year since most of the electricity produced by PV is self-consumed onsite.

The estimated Pay Back Time is expected to be between **7.2 (discount factor 0%) and 11.1 years (discount factor 8%)** depending on the discount factor which can be applied to the investment.

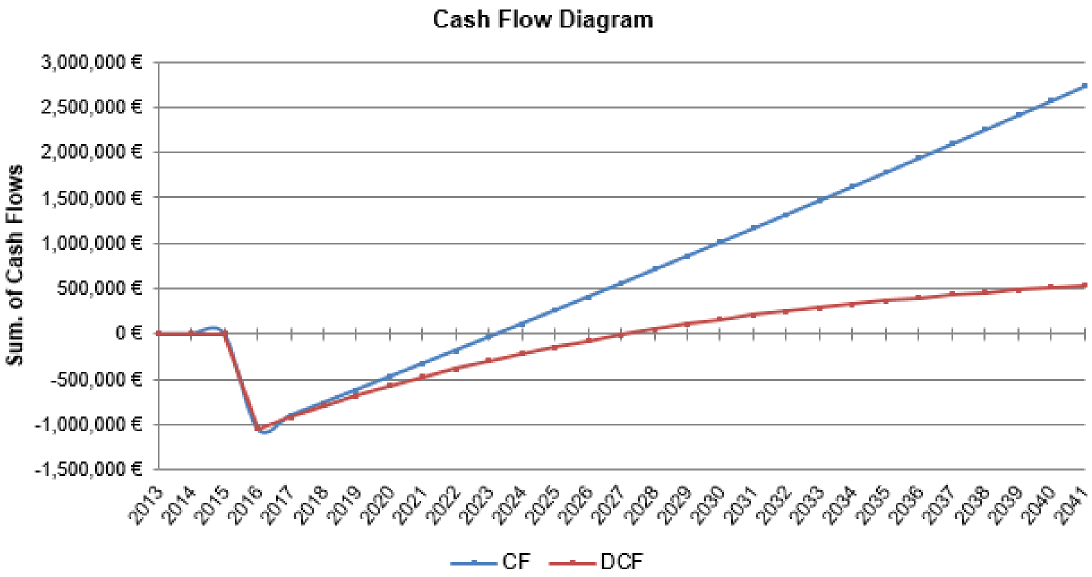


Figure 5-6 Cash flow diagram

5.6 Final considerations

Considering that in Coop Valbisagno both common areas and food store are owned and managed by Coop while shops and midsize stores are leased, the proposed solution set mainly focuses on common areas and food store. Since the shopping centre is under a major renovation process which is still in the planning phase, also interventions on HVAC system and cascade systems can be investigated.

The solution set proposed includes:

- Solution 1: efficient and dimmerizable lighting systems and cascade refrigeration
- Solution 2: booster
- Solution 3: heat recovery between HVAC and refrigeration water loops
- Solution 4: natural ventilation
- Solution 5: RES production from PV plant

The solution set package analysed leads to a reduction of 40% of electricity consumption compared to the baseline case, which corresponds to the renovation project. Up to 26% of energy savings can be achieved by passive and active solutions. Thanks to the PV plant we can have up to 19% of self-production and 100% of self-consumption.

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 1 million €, most of which is due to the PV plant. The total cost of investment of energy conservation and efficiency measures only is estimated at around 526,315 € (incl. tax).

Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 170,000 €/year and the revenues due to the sale of electricity to the grid from the PV plant are estimated as 200 €/year since most of the electricity produced by PV is self-consumed onsite.

The estimated Pay Back Time is expected to be between 7.2 (discount factor 0%) and 11.1 years (discount factor 8%) depending on the discount factor which can be applied to the investment.

6 Brent Cross (London – United Kingdom)

Brent Cross, Britain's oldest shopping centre, was created in 1976. It is the first stand-alone shopping centre in the UK. For 39 years it has been at the heart of the community, meeting the shopping needs of the 7 million people living in the Northern London and Hertfordshire areas.

Brent Cross has got one of the largest retail catchments in the UK with an annual footfall of 15 million visitors. This shopping centre offers 84,200 m² GLA with 118 tenants on two floors. Although it is smaller than more recent shopping centres, it has one of the largest incomes per unit area of retail space in the UK. Brent Cross has already been renovated in 1995, with additional shops and restaurants.

Figure 6-1. Brent Cross: building location (left) and simulation model (right)

6.1 Technological active-installation check-up

The building model is divided into 14 thermal zones according to space functions (internal gains level), HVAC systems, orientation and height. In the final energy model, individual shop units were grouped into thermal zones, following the IME methodology developed within the project. This mean that adjacent shops with similar properties and HVAC systems are merged. The internal room height is between 4.0 – 6.0 meter in most of the centre. The model comprises 9 Shop zones zoned by location and type to be able to evaluate lighting, heating, cooling and ventilation improvements, 2 Restaurant zones (food courts and cafes) to evaluate comfort in cafes with atrium location, 1 Food store (Waitrose) and 3 Anchor stores (52 % of GLA).

In relation to establishing the magnitude of the heat transmission between the zones through internal partitions, the air exchange between units are a significant part of heat exchange occurring between zones, which has consequences for estimating heating, cooling and temperature distribution within the centre.

In the baseline model air exchange is not considered between zones. As a result, temperatures may vary greatly between the zones and that heating and cooling may occur at the same time in the simulation. Heat transmission (conduction) through internal walls, will account for some of the exchange of heat between zones, evening out temperatures. By modelling internal partitions with poor insulation level, this effect may also compensate for the heat exchange which could be modelled through air exchange paths.

However, other physical effects normally cause temperature difference between parts of a centre and may lead to heating and cooling at the same time. The dominant airflow direction between zones, placement of ventilation inlets and outlets, thermostat placement and HVAC control algorithms, as well as the effect of additional partition walls between zones.

6.2 Analysis of energy consumption. Baseline simulation.

The graphs in Figure 6-2 to Figure 6-4 show the simulated and measured energy consumption.

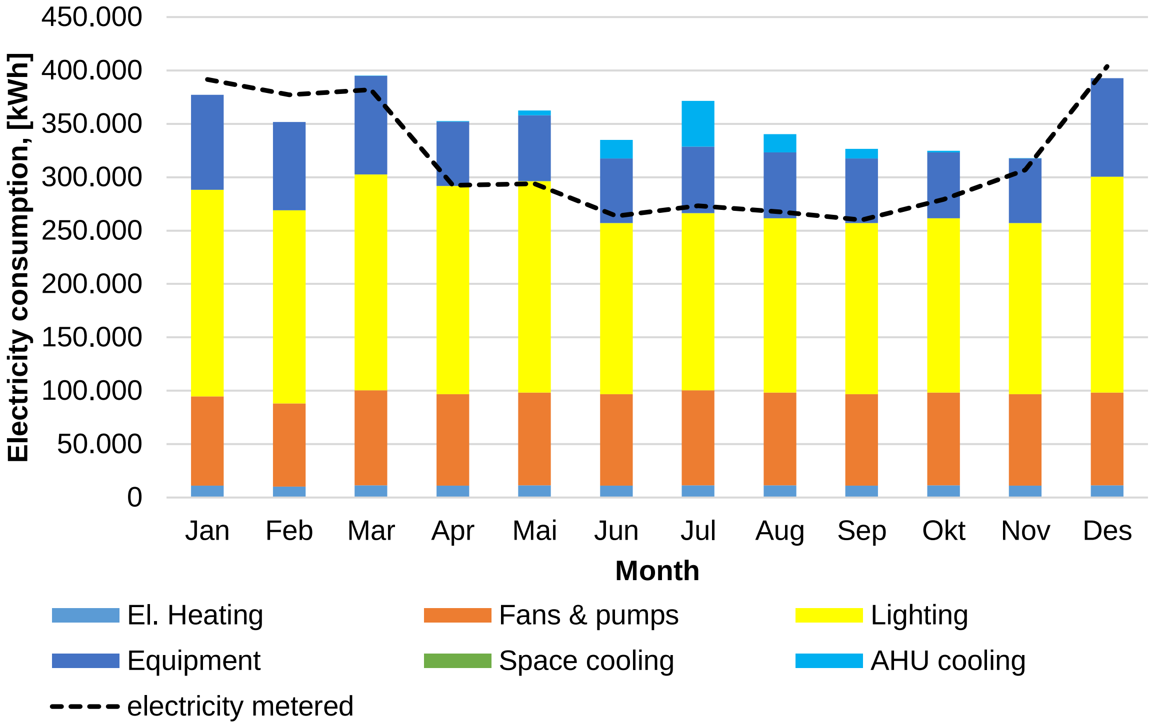


Figure 6-2. Predicted and measured landlord electricity use.

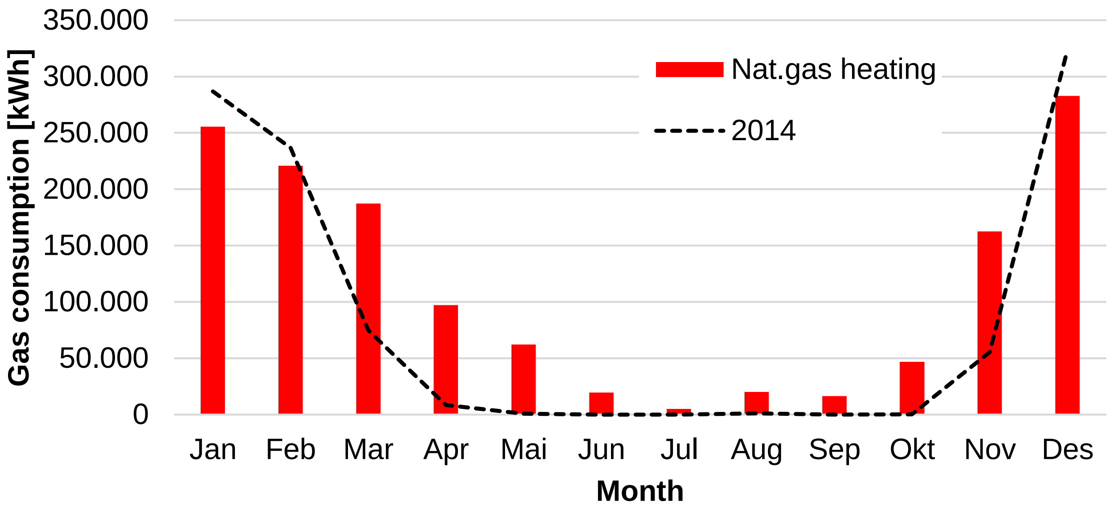


Figure 6-3. Predicted and measured landlord gas consumption.

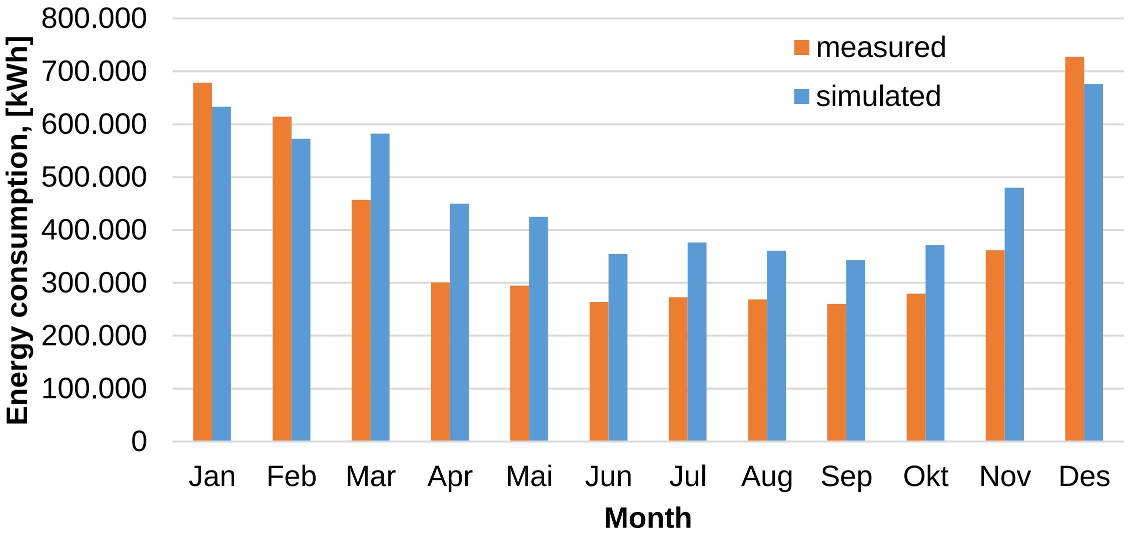


Figure 6-4. Predicted and measured landlord energy consumption.

6.3 Selection of suitable solutions

In this building, one solution-set has been identified with two different possibilities depending on the objective. In order to fulfil the 7-years payback, there is a limitation of the number of PV panels to be installed. The replicability of this solution-set would be high for those location where the installation of a PV system is cost-effective, because of the ambient conditions are favourable or even the installation of a renewable system could receive any kind of subsidies from the government. Table 6-1 reports a description of the solution set proposed for the Brent Cross reference building.

Table 6-1. Description of the solution set studied for the Brent Cross reference building.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Efficient lighting system and controls**	Lighting power density is reduced down to 4.5 W/m² in the common areas and galleries and to 18.1 W/m² in the vending area (shops, midsize stores, food store) because of the installation of LED lamps. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time. The concept of the zonal spatial distribution consisting of a comprehensive set of solutions that was applied let us expect savings in energy demand of around 60% against the initial situation. Application of newly developed LED high lumen retail wall washer which precisely illuminates merchandise with high efficacy and homogeneity. Glare will be reduced due to very good longitudinal glare control. Beam angle was extended to 120° in order to illuminate not only the merchandise wall but also the area in front to enable optimal examination of goods by customers. Introduction of an evening scenario with warm-white light colour of 2700 K und reduced intensity. This lighting scene considers human biorhythm as the indoor room atmosphere is coupled with the natural outdoor lighting environment. Sophisticated control and monitoring strategy that enables highly differentiated space areas.	40% cooling need reduction	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping centre.
2	**Appliances replacement**	The appliances will be replaced in maintenance cycles with high efficiency products.	Electricity savings of 4629 MWh per year.	The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.
3	**PV system**	55000 m² PV system (almost) horizontally installed on roof (9MWp). Optional: Battery system installed in technical room.	Almost 8700 MWh electricity production.	Less overheating during summer due to reduced internal heat gains.

6.4 Energy savings

The graph in Figure 6-5 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described above. The figures below show primary energy savings of the solution set based on solution for lighting, appliances and RES. The primary energy for this solution set could be reduced by 75%.

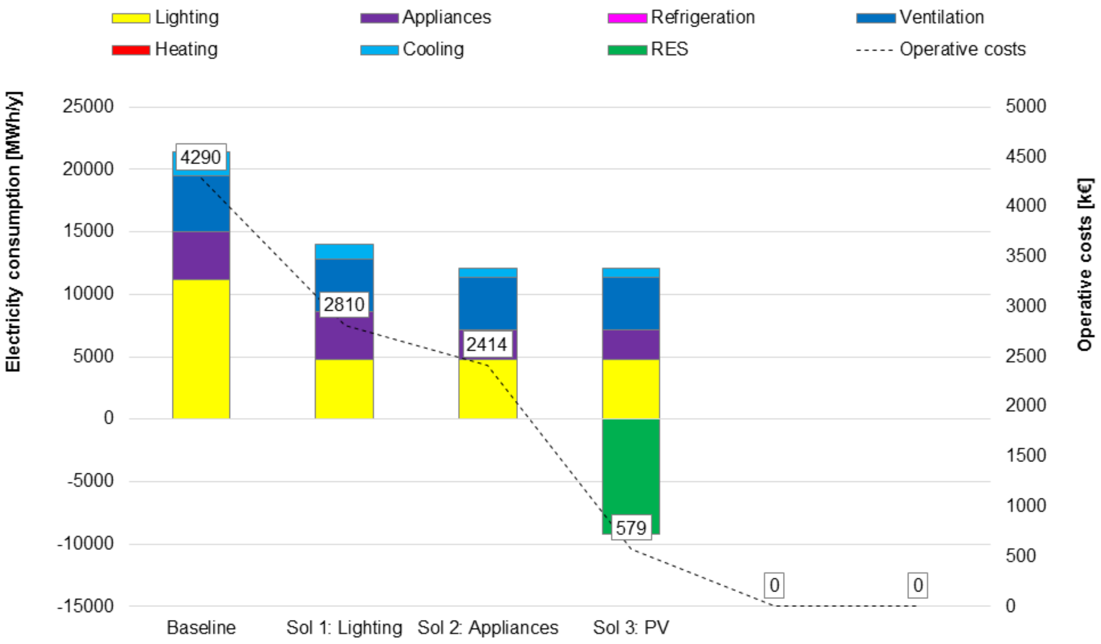
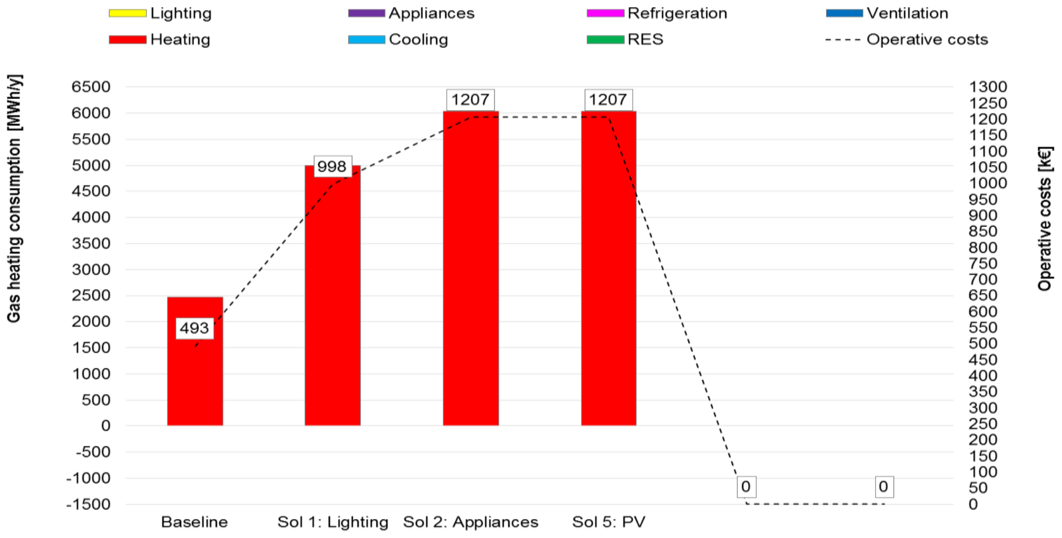


Figure 6-5. Yearly energy consumption (electricity) in Brent Cross shopping center.



. Figure 6-6. Yearly energy consumption (gas) in Brent Cross shopping center.

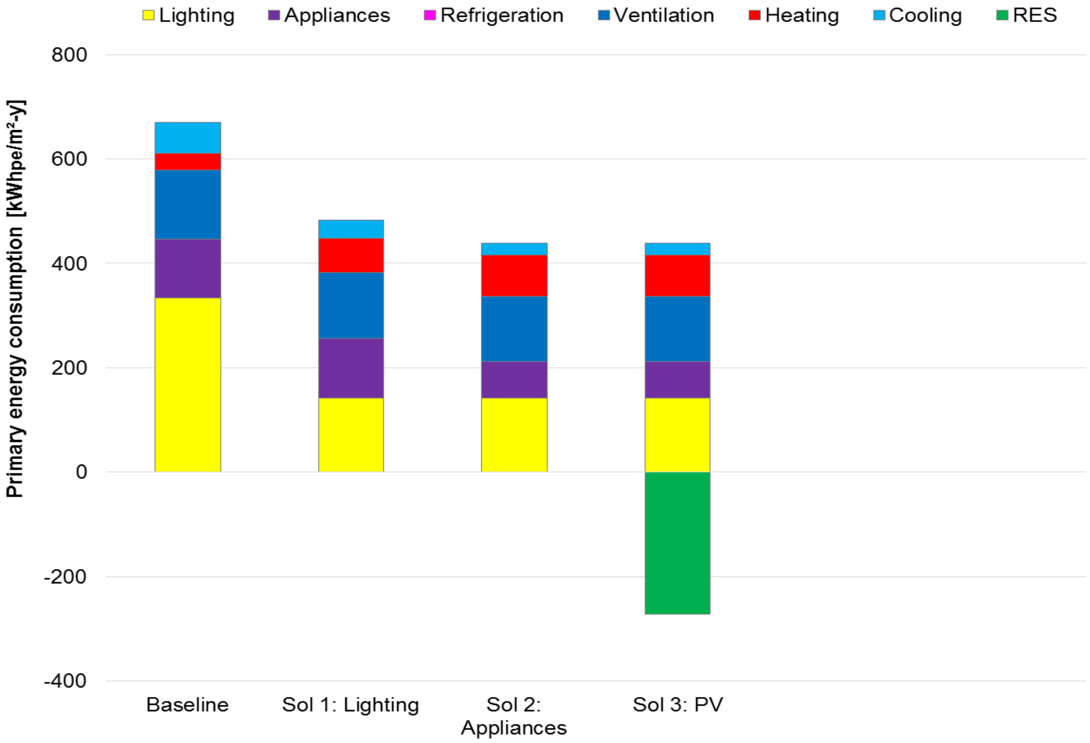


Figure 6-7. Primary energy consumption in Brent Cross shopping center.

6.5 Economic analysis

The results of the economic study over the 25 years period studied are shown in the Figure 6-8.

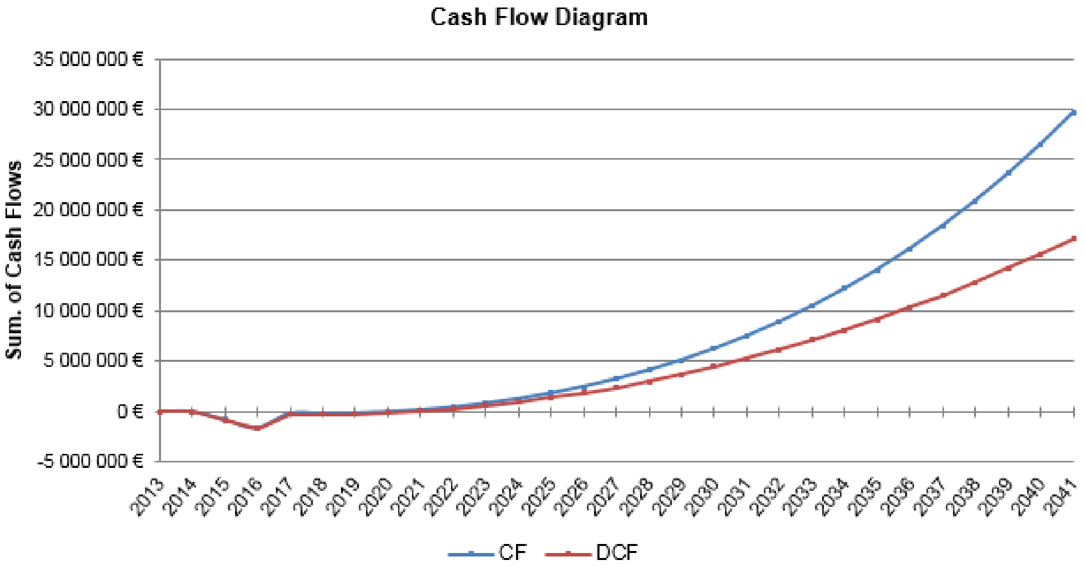


Figure 6-8. Cash flow diagram.

Table 6-2 – Economic evaluation summary

Solution-set	Investment €	Operation costs savings 1st year, €	DPB years	NPV €	ROI %
Efficient lighting system and controls, appliances replacement, PV system	10,851,105	1,876,000	7	17,152,968	23.5

6.6 Final considerations

The building energy simulation model was set-up to enable us to predict energy consumption and loads on hourly basis, as well as indoor conditions for each of the reference building. With the help of the model it was possible to for define management strategies. We used the actual consumption data, when available, for plausibility check to validate the simulation results usability.

We have tested and quantified the potential energy savings of energy efficiency measures including envelope elements, efficient lighting systems, daylighting systems, ventilative cooling, HVAC+R layouts, renewable energy production and storage systems. Furthermore, we were also analysing the energy efficiency measures from economical point of view since we aim at defining cost-effective and energy efficient solutions for the retrofit of shopping centres.

The solution set proposed for the retrofit consists of the following measures:

- Solution 1: Efficient lighting system and controls
- Solution 2: Appliances replacement (Reduction of installed power for escalators, etc.)
- Solution 3: PV system (PV plant 5.5 MWp)

This solution-set offers 55% of primary energy consumption reduction with an investment of 10,851,105 € and less than 7 years of payback time as established.

7 Katané (Catania - Italy)

The shopping mall Katané in Catania (Sicily) owned by IGD and Ipercoop Sicilia is a medium size regional shopping centre opened in 2009 (Figure 7-1) and located in a suburban context (Figure 7-2). A two floor gallery with more than 60 retail units offers a GLA of 27,521 m² of which 8,000 m² are dedicated to a hypermarket. The shops' gallery connects two atriums with skylights. The roof of the commercial centre is a private parking area for the shopping mall workers. Public parking areas are located at ground floor and part of the first floor.

The climate is cooling dominated. The centre is opened from 9:00 until 22:00, seven days per week.

Figure 7-1. View of the main facade of the shopping mall.

Figure 7-2. Satellite view. Source: Google map.

The exterior walls and the roof are in precast concrete with 10 cm external insulation. The walls are painted in ochre colour, corresponding to circa 0.7 solar absorptance. The exterior roof is partially occupied by a parking lot and therefore paved. The rest of the roof is covered by a bitumen waterproofing membrane.

According to the information provided by IGD, lighting power density is 80 W/m² in the shops, 50 W/m² in the midsize stores, 25 W/m² in the food store, 20 W/m² in the common areas, 20 W/m² in offices, 15 W/m² in the warehouses and 2.2 W/m² in the parking area. Atriums and part of the central gallery are daylighted thanks to the skylights.

7.1 Technological active-installation check-up

The common areas are conditioned with three rooftop air conditioning units with a COP of 2.71. This value is reduced by 87% taking into account control, distribution and emission losses. The units recover part of the exhaust air and mix it with outdoor air: on average 70% of the supplied air is recirculated air and 30% is outdoor fresh air. An air extractor balances the mass flow. The system works at constant airflow rate during the opening hours and it is attenuated overnight. Full recirculation mode is set in the first opening hours until the set-point indoor temperature is reached. The airflow is regulated by thermostats, but there is no external temperature sensor.

The midsize shops are conditioned by means of a rooftop air conditioning unit each. No information are available regarding the units' regulation mode.

Three air handling units with heat recovery provide air changes to the shops and fan coils served by two air to air heat pumps are conditioning the spaces. No information on heat recovery efficiency is available. We assumed therefore a 60% heat recovery efficiency.

The technical specification on the heat pumps are:

- Cooling power = 750 kW
- Power absorbed in cooling mode = 250 kW
- Heating power = 820 kW
- Power absorbed in heating mode = 240 kW

Therefore, we considered the following efficiencies to estimate the electricity consumption due to the shops' air conditioning: EER = 3.6; COP = 4.

The difference between outdoor temperature and temperature set-points is also taken into account in the hourly estimation of heating and cooling electricity consumption.

Considering a constant flow rate during the opening hours, we derived the air changes from the conditioning and air handling units' airflow and the zone volumes. A ventilation setback lowers ventilation rates by 70% during non-occupied time.

No information about the HVAC and refrigeration plant layout of the hypermarket are available, neither the energy consumption due to refrigeration is measured.

A specific fan power of 0.65 Wh/m^3 in shops and common areas, 0.45 Wh/m^3 in midsize stores and 0.75 Wh/m^3 in the food store is considered to estimate the electricity consumption of ventilation.

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

The heating demand of the market has been calculated by imposing a set point temperature of 21°C from 9 am to 9 pm and a setback temperature of 15°C during every day. The cooling set point temperature varies between 23°C and 26°C, depending on outdoor temperature, from 9 am to 9 pm. The heating and cooling system is turned off during the night. No additional air humidification is considered during the winter time.

7.2 Analysis of energy consumption. Baseline simulation.

The graph in Figure 7-3 represents the monthly specific energy balance over the whole building. The total heating demand is around 50 kWh/m^2-y, whereas cooling demand is aorund 150 kWh/m^2-y.

Cooling season starts from week 18 (May) and ends in week 43 (October), even though some cooling need can occur during winter season mailny in the shops because of their high lighting power density.

Internal gains are dominant among the positive items of the energy balance. Ventilation losses contribute positively to free cool the building during middle seasons (week 18-24 and week 36-43), but cause an increas of cooling need during July and August (week 25-35).

Thermal losses due to infiltration rates are significant in winter time and a reduction of infiltration rates through a better control of door opening or envelope air tightness improvement can potentially reduce heating demand.

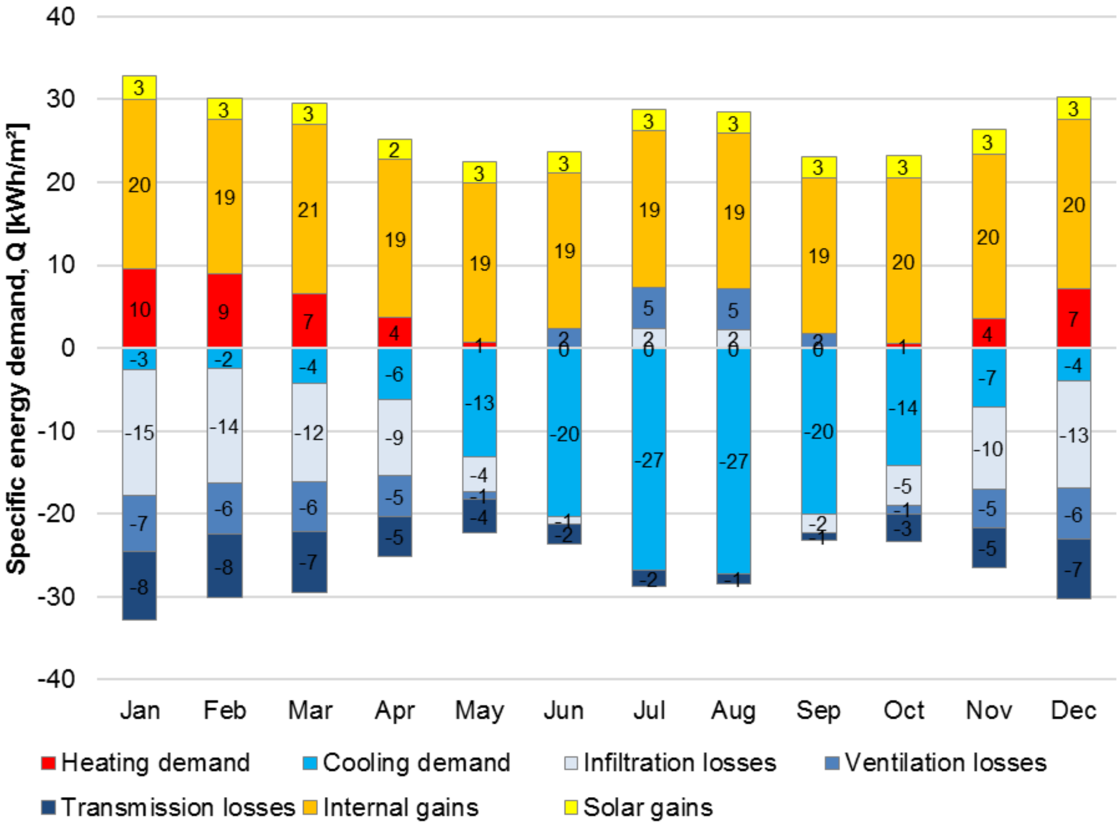


Figure 7-3. Monthly energy balance – whole building.

The graph in Figure 7-4 represents the electricity consumption divided by zone function. The shop zones (SHP) have the highest electricity consumption due to the high lighting power density.

According to our model predictions, the most affecting energy use are due to HVAC systems (45% of the total electricity consumption), followed by lighting (39%), refrigeration (9%) and other electric equipment (7%).

Total electricity consumption amounts at 19,222 MWh which corresponds to 698 kWh/m²-y considering the conditioned area of 32,044 m².

With a primary energy factor of 2.046 kWh_{pe}/kWh_{el}, the total primary energy consumption amounts at 1,429 kWh_{pe}/m^2y.

Considering the carbon factor as 0.521 kg_{CO_2eq}/ kWh_{el}, the carbon emissions of the shopping centre amount to 10,015 $tons_{CO_2eq}$ per year.

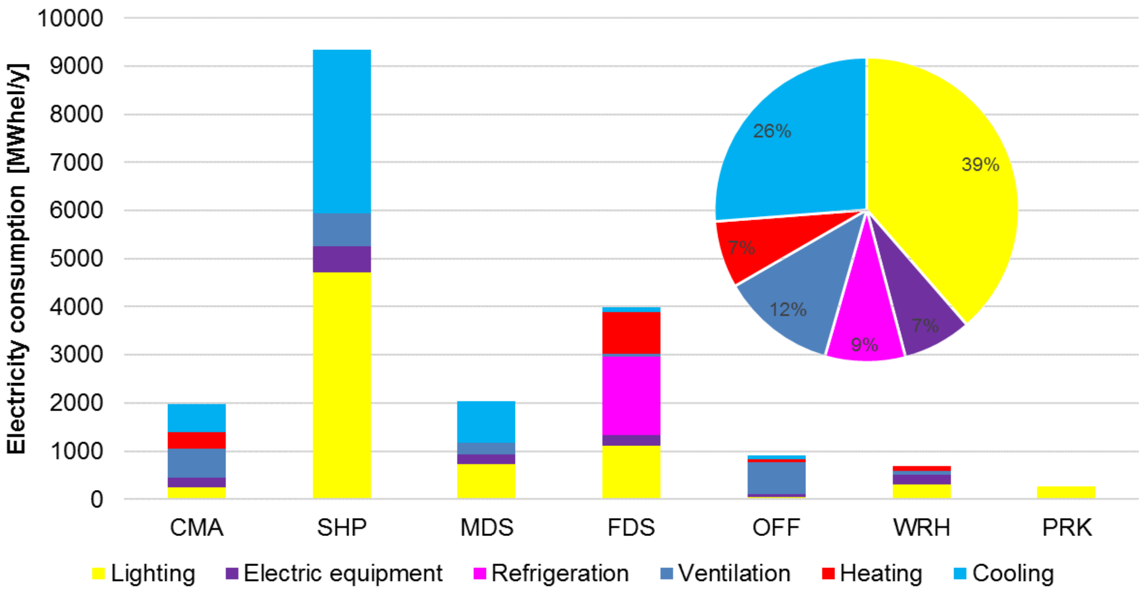


Figure 7-4. Electricity consumption for each group of zones.

IGD is responsible for the facility management of the common areas. Shops and food stores are leased by IGD and managed by the respective tenant. Lease agreement lasts generally 5 year. Tenants contract for electricity services and IGD does not have access to their electricity consumption because of privacy reasons. Tenants pay a fixed percentage of the shopping centre's utility bill and maintenance for parking and common areas and for shops air conditioning based on the square footage.

Since the solution set is addressed to IGD, it is worth to break down the energy consumption data for common areas (Figure 7-5). The air conditioning and ventilation accounts for over ¾ of the total energy consumption. Internal and external lighting as well as plug loads accounts for almost the same amount of energy.

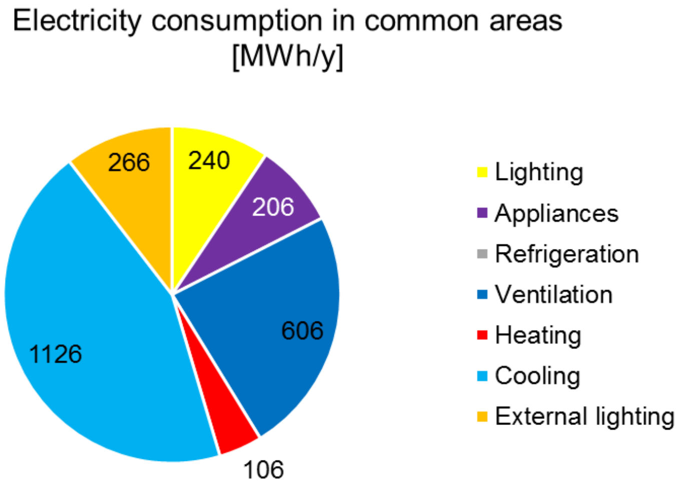


Figure 7-5. Electricity consumption breakdown for common areas.

The overall electricity consumption for common areas is estimated at 2,915 MWh which results in monthly average operational expenses of around 36,000 €, considering an electricity price of 0.15 €/kWh. Tenants pay a fixed percentage of the shopping centre's utility bill and maintenance for parking and common areas and for shops air conditioning based on the square footage.

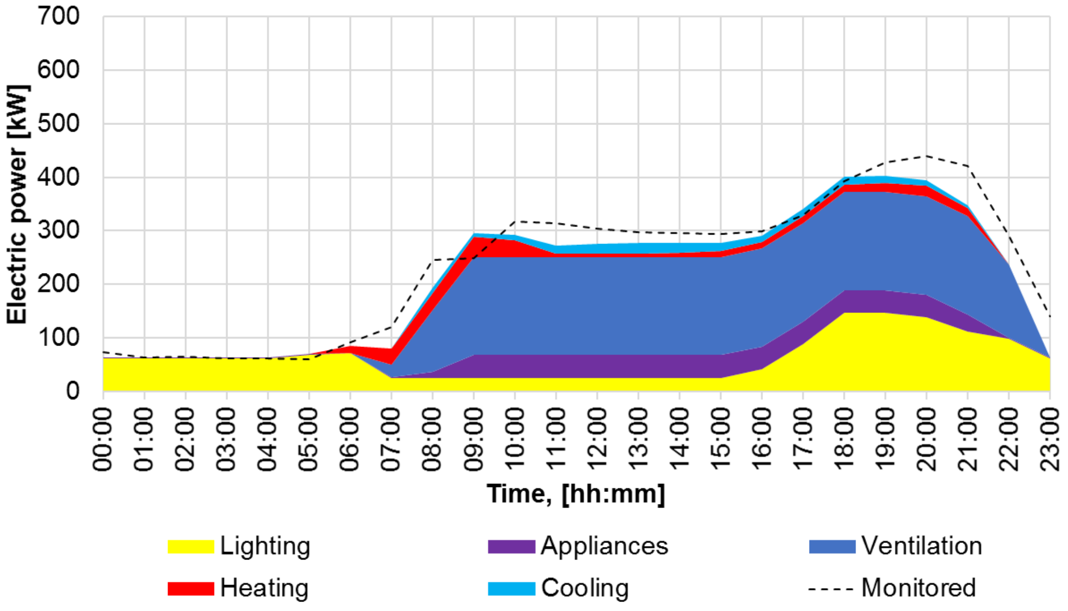


Figure 7-6. Average daily profile of electricity consumption of common areas in winter from simulation results compared to the data measured in 2014.

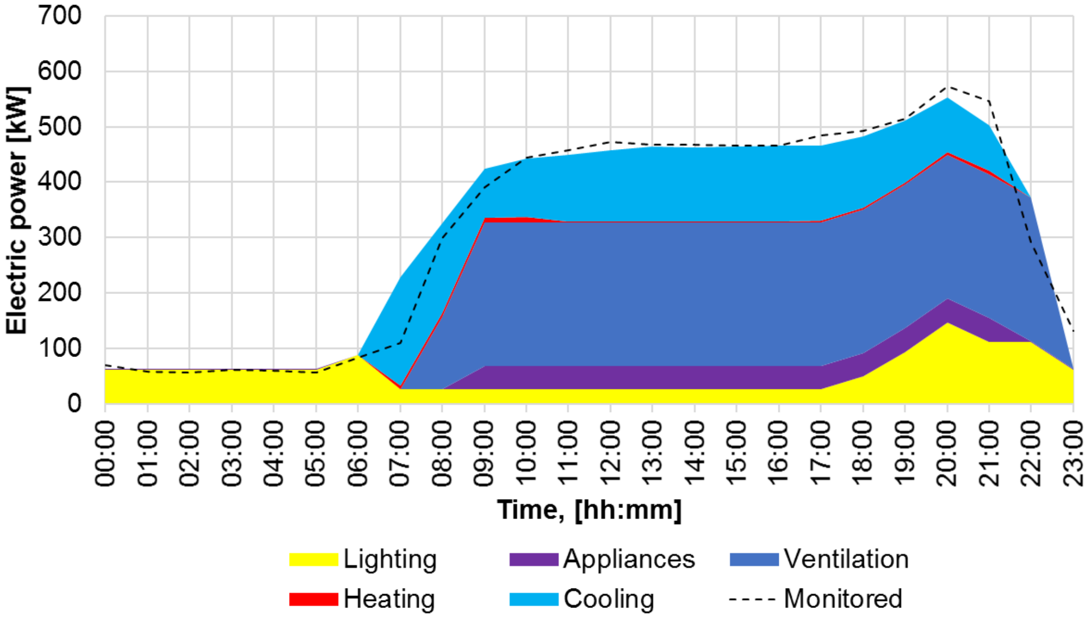


Figure 7-7. Average daily profile of electricity consumption of common areas in summer from simulation results compared to the data measured in 2014.

The model is calibrated on the basis of monthly and hourly electricity consumption (Figure 7-6 and Figure 7-7) of common areas (external lighting of parking lots and shops AHU is also included) in 2014. Since no monitored data are available from tenants, the shops and food store zone model cannot be calibrated.

According to the monitored data, the total electricity consumption of the common areas in 2014 amounts at 2,433 MWh. The calibrated model predicts a total electricity consumption of 2,915 MWh.

7.3 Selection of suitable solutions

Considering that Katane is quite a new shopping centre (built in 2009), there is no plan for restyling and therefore the proposed solution set mainly focuses on the management of the existing features and component in the most efficient way. Solutions with low investment costs (i.e. HVAC controls, natural ventilation) or with low pay back time (i.e. lamps replacement – 13 months PBT) are preferred instead of solutions requiring a shopping mall restyling (i.e. envelope insulation). Table 7-1 reports a description of the solution set proposed for the Katane’ reference building.

Table 7-1. Description of the solution set studied for the Katane' reference building.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Efficient lighting system and controls**	Lighting power density is reduced down to 4.5 W/m² in the common areas because of the installation of LED lamps. Zonal lighting concept reduces ambient lighting, accentuates zones with higher intensity and maintains the perceived brightness impression. Advanced controls on light colour and dimmerizable lights allow to reduce lighting intensity during night milieu, after sunrise during opening time.	31% reduction of lighting electricity consumption 19% cooling need reduction 36% heating need increase	Glare is reduced and we manage to bring the indoor lighting condition closer to outside natural situation (warm-white colour in the evening). Therefore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall. Lighting levels in the shops can be lower keeping a stable visual comfort and perception since the lighting levels in the shops are harmonized with the ones in the common areas.
2	**Heating and cooling setpoint management**	Assuming that costumers can adapt to slightly higher indoor temperatures in summertime and lower indoor temperatures in winter time, we set more relaxed comfort temperature ranges. Heating setpoint is lowered by 1K (from 21°C to 20°C) and cooling setpoint varies between 24°C and 27°C depending on outdoor temperature.	Energy consumption for common areas air conditioning is expected to decrease by 20%.	Impact on thermal comfort can be monitored by means of measurement and interviews campaigns.
3	**Demand control ventilation (DCV)**	The amount of outdoor ventilation is adjusted depending on the inflow of people and/or the level of CO_2. Therefore, fresh air is provided only when it is needed, i.e. higher inflow times (between 11am and 13 am, between 17pm and 20pm).	Up to 53% less energy consumption for ventilation	Even though the amount of outdoor ventilation might be lower than baseline solution, no impact of indoor air quality is expected because air changes are delivered just when they are needed.

Solutions		Description	Expected energy savings	Expected impact on comfort
4	**Natural ventilation**	Natural ventilation through openable windows in the atria and gallery skylights help vent out stale air in the summer. Combining the effect of opened sliding doors and skylight openings can enhance stack ventilation and ventilate/cool the common areas. The connection of opening control to the iBEMS and the integration of inverters automated by the iBEMS would allow to switch off the mechanical ventilation and cooling in the common areas when natural ventilation is activated and to introduce a more sophisticated control strategy.	Cooling demand reduction by 1% in the common areas Electricity consumption due to ventilation of the common areas reduced by 13%	Increasing the air velocity within the indoor environment improves the comfort sensation of customers at high indoor temperatures. During shoulder season, natural ventilation provides higher ventilation rates than demand control ventilation ensuring a higher IAQ.
5	**PV plant on gallery roof and parking canopies**	208 kWp PV plant is installed on the roof gallery and another PV plant of 372 kWp is installed on new parking canopies on the roof.	The PV plant is expected to produce 888 MWh/y of electricity. The yearly simulation performed using consumption data from common areas with energy conservation and efficiency measures gave the results of around 40% of self-production, 60% of self-consumption.	The PV installation will create shaded parking lots, which are preferred from customers especially during the summer period. Lower ceiling surface temperature improves thermal comfort, especially in the offices on the roof

7.4 Energy savings

The graph in Figure 7-8 shows the actual yearly final energy consumption of the common areas in the baseline model and the potential energy savings of the energy efficiency measures described in paragraph 7.3.

The solution set package analysed leads to a reduction of 58% of electricity consumption. Up to 40% of energy savings can be achieved by just optimizing heating, cooling and ventilation controls. Thanks to the PV plant we can have up to 40% of self-production and 60% of self-consumption.

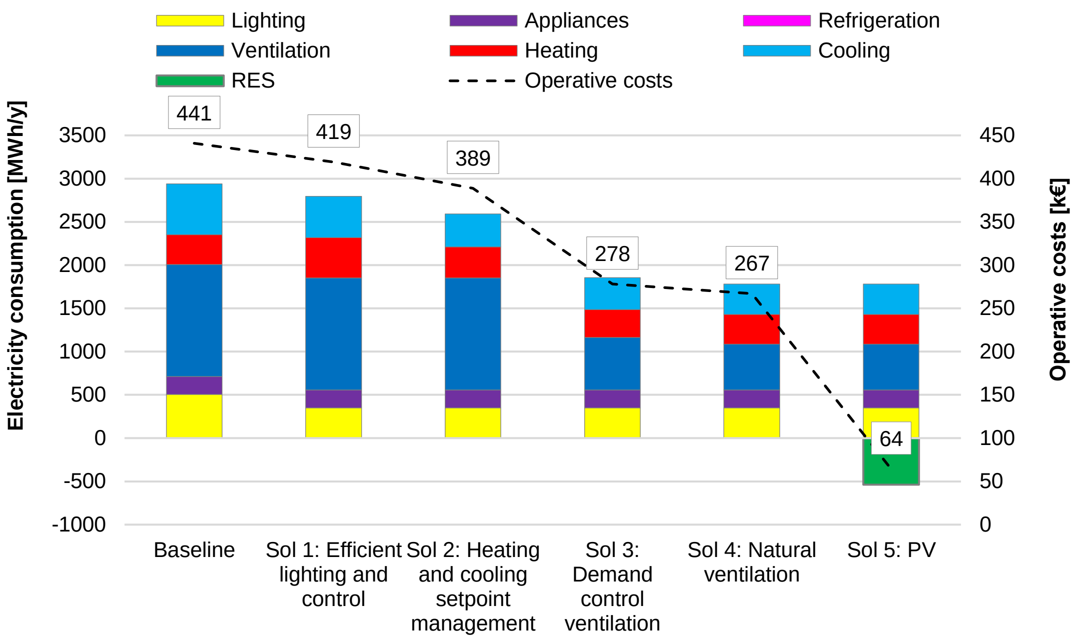


Figure 7-8. Yearly final energy consumption of the common areas.

The graph in Figure 7-9 shows the actual yearly primary energy consumption of the common areas in the baseline model and the potential primary energy savings of the energy efficiency measures described in paragraph 7.3, considering a primary energy factor of 2.046 kWh_{pe}/kWh_{el}. Since the systems are all electric, the percentages of primary energy reduction referred to the baseline are the same as the one estimated for the electric energy savings.

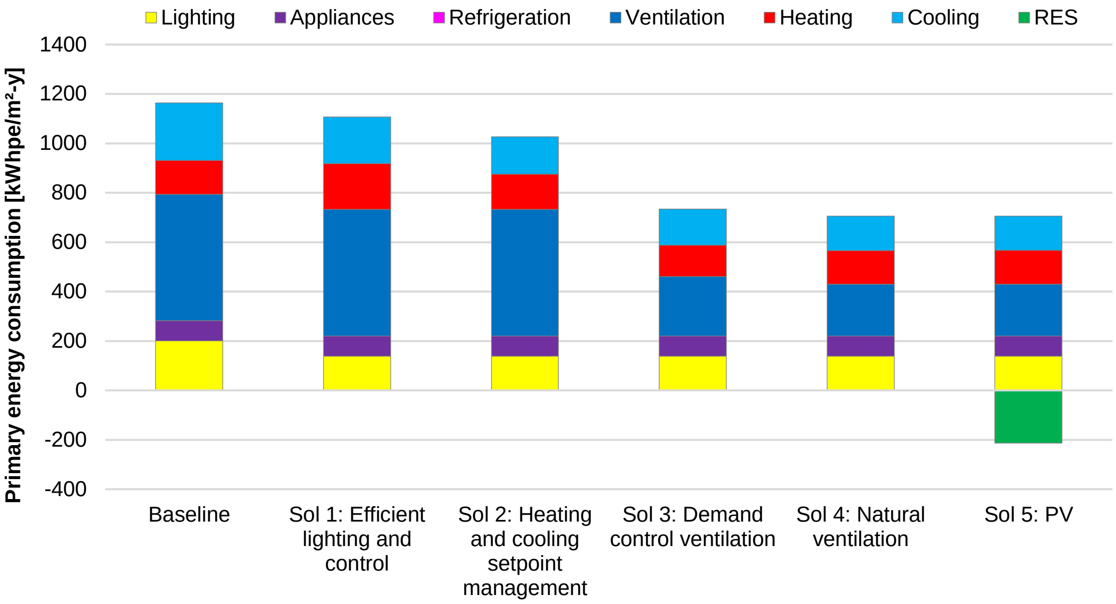


Figure 7-9. Yearly primary energy consumption of the common areas.

7.5 Economic analysis

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 2 million €, most of which is due to the PV plant. The total cost of investment of energy conservation and efficiency measures only is estimated at around 208,000 € (incl. tax).

Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 174,000 €/year and the revenues due to the sale of electricity to the grid from the PV plant are estimated as 121’900 €/year.

The estimated Pay Back Time is expected to be between **5.1 (discount factor 0%) and 6.8 years (discount factor 8%)** depending on the discount factor which can be applied to the investment.

The results of the economic study over the 25 years period studied are shown in the Figure 7-10.

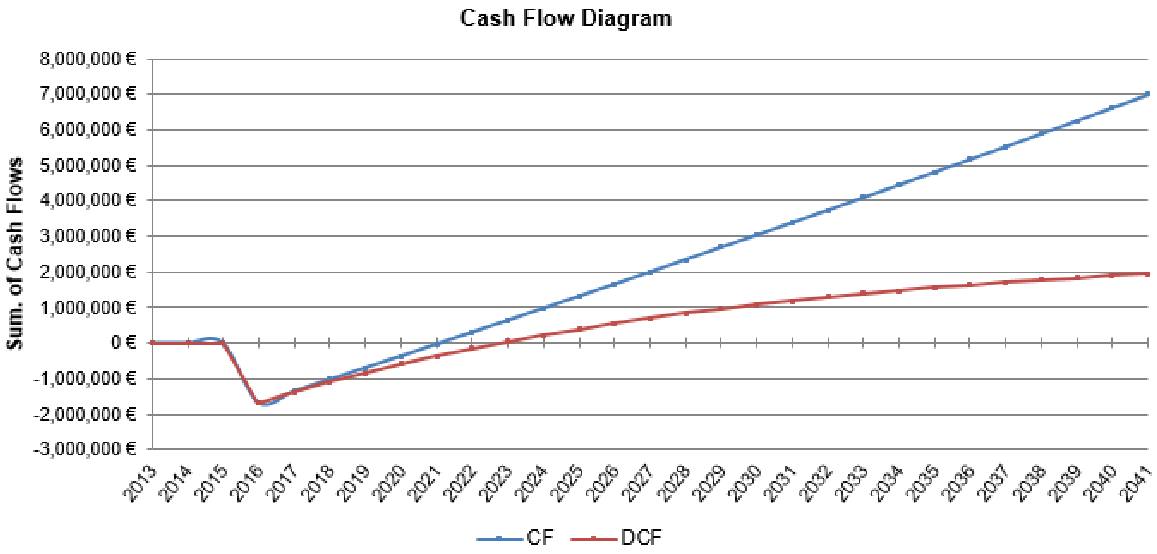


Figure 7-10. Cash flow diagram.

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The Pay Back Time of energy conservation and efficiency measures only can be lower than 2 years.

7.6 Final considerations

Considering that Katane' is quite a new shopping centre (built in 2009), there is no plan for restyling and therefore the proposed solution set mainly focuses on the management of the existing features and component in the most efficient way. Solutions with low investment costs (i.e. HVAC controls, natural ventilation) or with low pay back time (i.e. lamps replacement – 13 months PBT) are preferred instead of solutions requiring a shopping mall restyling (i.e. envelope insulation).

Since shops and food store are leased by IGD and each tenant manages their shop on their own, the study is focused on common areas only.

The solution set proposed includes:

- Solution 1: efficient and dimmerizable lighting systems
- Solution 2: heating and cooling setpoint management
- Solution 3: demand control ventilation
- Solution 4: natural ventilation
- Solution 5: RES production from PV plant

The solution set package analysed leads to a reduction of 58% of electricity consumption. Up to 40% of energy savings can be achieved by just optimizing heating, cooling and ventilation controls. Thanks to the PV plant we can have up to 40% of self-production and 60% of self-consumption.

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 2 million €, most of which is due to the PV plant. The total cost of investment of energy conservation and efficiency measures only is estimated at around 208,000 € (incl. tax).

Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 174,000 €/year and the revenues due to the sale of electricity to the grid from the PV plant are estimated as 121,900 €/year.

The estimated Pay Back Time is expected to be between **5.1 (discount factor 0%) and 6.8 years (discount factor 8%)** depending on the discount factor which can be applied to the investment. The Pay Back Time of energy conservation and efficiency measures only can be lower than 2 years.

8 Donauzentrum (Vienna - Austria)

The “Donauzentrum” shopping mall opened first in 1975 with 22,800 m² of retail space while today the total area occupied is around 130,000 m² including over 260 retail, dining and entertainment business. Since 1975 the mall has been several times extended and retrofitted reaching the final configuration in 2010 as shown in Figure 8-1. The two-floor building blocks flank Wagramer Straße and connected by a shop-gallery bridge. The BT4-5 second floor is partially occupied by an external multi-storey car park while on the third floor there are offices and a hotel.

Up to now the oldest part is the BT4-5 since in 2000 the BT1-3 was refurbished with a new roof skylight allowing daylighting. The newest and most efficient part is the BT7, built in 2010 with two big galleries and partially glazed roof for daylighting exploitation. The lighting system is controlled according to the illuminance level recorded by some sensors; however the control strategies are not clearly defined resulting in artificial light use even when daylighting is available. The shopping mall direction is continuously working to improve the mall energy efficiency. For example, in 2014 fluorescent lamps have been replaced with LED technology in both the common areas of BT7 and BT1-3/9 reducing the common areas electrical consumption by 18%.

BT4 southern common area roof is partially glazed with operable windows used for smoke ventilation only. The same windows concept is applied in the above ground corridors that connect BT4-5 with BT1-3/9.

Regarding the building envelope, it is a very compact building with an average thermal transmittance of 0.512 W/m²K. The higher percentage of Window-to-Wall Ratio (WWR) faces north and west orientation, 44% WWR on north façade and 30% WWR on west facade respectively. The BT7 façade facing north has 80% WWR (Figure 8-2). The latest retrofit covered the façade facing Karan U-Bahn station with LED which allows playing with the entire headboard colour (Figure 8-3).

The mall is opened 6 days per week with 11 hours per day except on Saturday that is opened for just 8 hours. On Sunday it is usually closed as also during the National holidays (10 day all over the year).

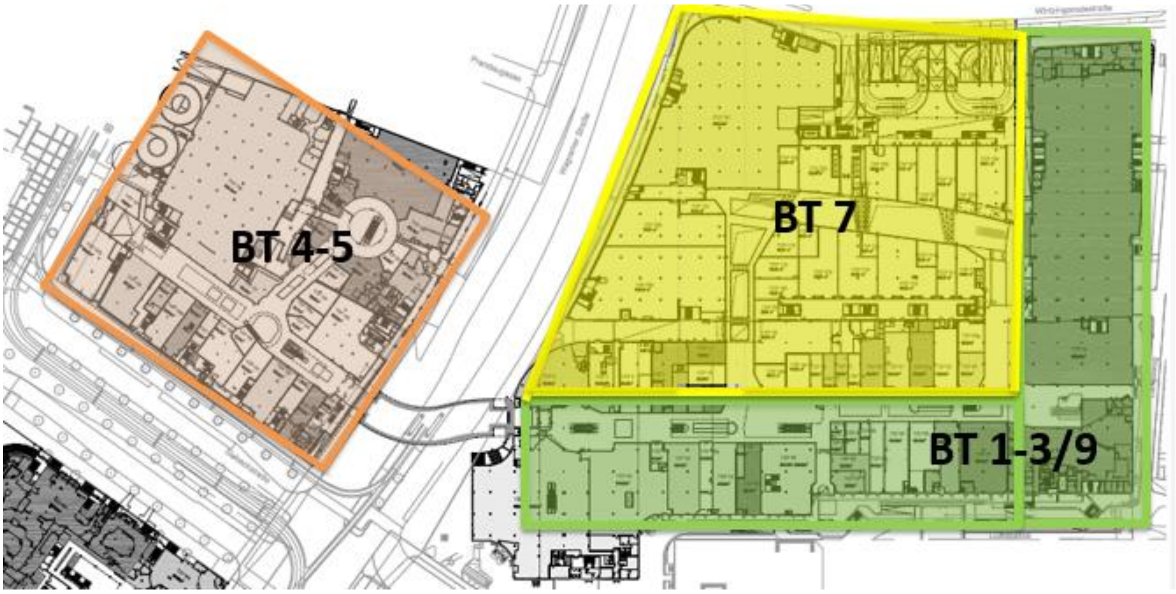

Figure 8-1. Donauzentrum building units.

Figure 8-2. North-West view of BT7

Figure 8-3. South-Est view of BT 4-5

8.1 Technological active-installation check-up

Common areas and tenants are served by the same HVAC system .The system recovers 80% of the exhausted air and mix it with the outside fresh air. Air extractors balance the mass flow. The system is a constant air volume system and the inlet air temperature is regulated by an external sensor temperature. If the outside temperature is lower than 13°C the inlet air temperature is the one resulting from the mixture between the temperatures of the recirculated air, assumed to be 80% of the total air flow, and the outside temperature. When the outside temperature is indeed greater than 13°C, the supplied air temperature is equal to the outside one. Heat recovery is taken into account by setting 60% and 40% efficiency of the heat exchanger, depending on the different blocks. This control has been set for all the days in which the shopping centre is opened.

There is a CO_2 based ventilation that regulates the airflows based on the occupancy of the shopping mall. Being the whole system a constant air volume one, the airflows can just varies from the minimum to the maximum values. Since there were no information about the real airflows provided, for the modelling we follow the prescription of the European standard EN 15251, referring to a Cat II retail building (EN ISO 15251, 2008).

The mall is connected to the local district heating system which provides thermal energy for heating the whole mall. A typical dry cooler provides cooling to the newest part BT7. In BT1-3/9 and BT4-5 cooling is generated by a standard chiller coupled with an open cooling tower.

The power plants capacities provided by the energy manager are collected in Table 8-1.

Table 8-1. Heating and cooling system capacities

	BT 1-3/4-5/9	BT 7
Heating system capacity (kW)	8718	3500
Cooling system capacity (kW)	8694	4180

In order to estimate the electricity consumption of the HVAC system, the efficiencies in Table 8-2 are considered.

Table 8-2. HVAC efficiencies considered.

	Ventilation specific power	EER	Heat Recovery	District Heating
BT 1-3-4-5-9	1.5 Wh/m³	3	60%	0.9
BT 7	0.9 Wh/m³	3.5	60%	0.9

The heating demand of the mall has been calculated by imposing a set point temperature of 18°C from 9 am to 8 pm and a setback temperature of 13.5°C during night. The cooling demand has been calculated by imposing a set point temperature of 25°C from 9 am to 8 pm. The cooling system is turned off during the night. No additional air humidification is considered during the winter time.

The heating and cooling system are shut off on Sunday and closing days.

8.2 Analysis of energy consumption. Baseline simulation.

The graph in Figure 8-4 represents the electricity consumption divided by zone function. The shop zones (SHP) have the highest electricity consumption due to the high lighting power density.

According to our model predictions, the most affecting electrical energy use are due to lighting (39% of the total electricity consumption) and ventilation (27%) followed by other electric equipment (16%), by and refrigeration (11%) and finally by cooling (9%). Heating consumption since it is served by district heating cannot be compared with the electrical consumption.

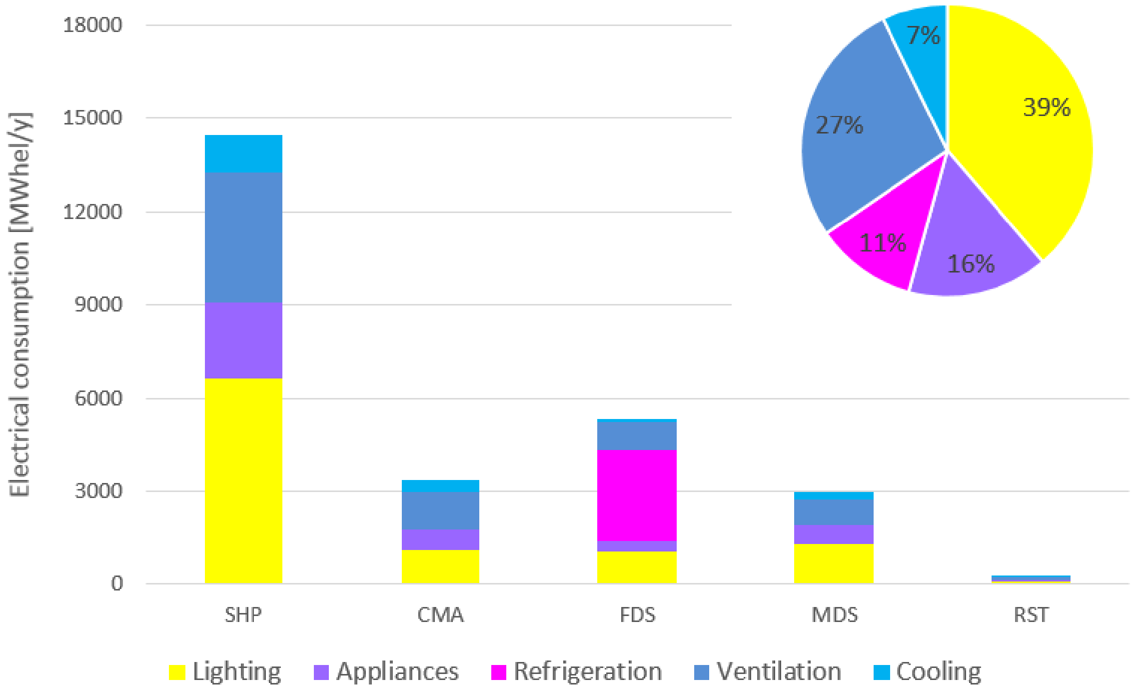

Figure 8-4. Electricity consumption for each group of zones: Common Areas (CMA), Shops (SHP), Midsize store (MDS), Food store (FDS), Restaurant (RST)

Total electricity consumption amounts at 26,392 MWh/y which corresponds to 285 kWh/m^2-y considering the conditioned area of 92,621 m^2. These data refer to a model based on climatic condition of a typical meteorological year (TMY).

Figure 8-5 and Figure 8-6 show the comparison between the simulated and real consumption in 2013 respectively for electricity and heating consumption.

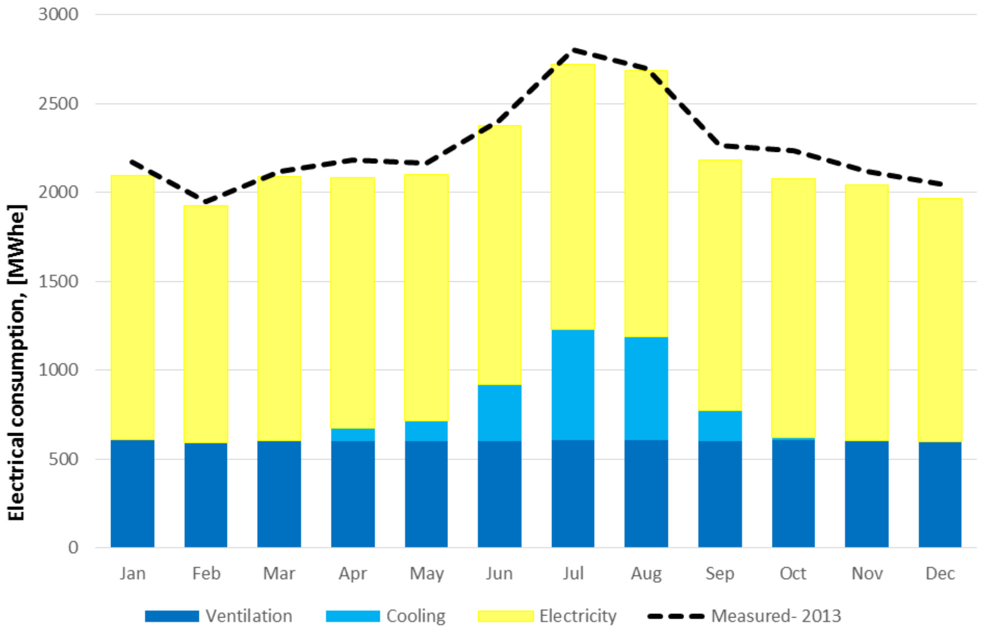

Figure 8-5. Monthly profile of electricity consumption from simulation results compared to the data measured in 2013 for the entire mall.

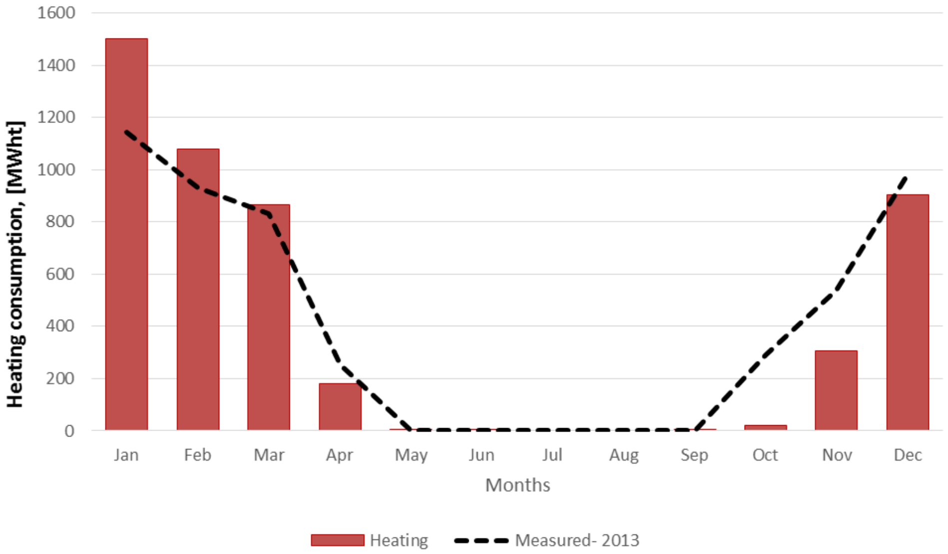

Figure 8-6. Monthly profile of heating consumption from simulation results compared to the data measured in 2013 for the entire mall.

According to the monitored data, the total electricity consumption for all the zones (BT 7 and BT 1-3-4-5-9) in 2013 amounts at 27,153 $\mathrm{MWh_{el}}$ while the heating consumption is 4,970 $\mathrm{MWh_{th}}$. The calibrated model predicts a total electricity consumption of 26,336 $\mathrm{MWh_{el}}$ and a heating consumption is 4863 $\mathrm{MWh_{th}}$. Considering a conditioned area of 92,621 $\mathrm{m^2}$ the simulated electrical consumption is 284 $\mathrm{kWh/m^2}$-y while the heating simulated consumption is 53 $\mathrm{kWh/m^2}$-y.

8.3 Selection of suitable solutions

Donauzentrum shopping mall is a very huge shopping centre and the management of the shopping centre is investing regularly on sustainable solutions for the shopping centre. Considering this evidence the study took into account both solutions already planned by the energy retrofit plan of the shopping mall (e.g. replacement of new efficient lighting and the exploitation of natural ventilation within common areas) and other low investment cost solutions(e.g. controlling cooling set-point of tenants areas) or solution with low pay back time (e.g. improvement of appliances efficiency, revolving doors). Table 8-3 reports a description of the solution set proposed for the Donauzentrum reference building.

Table 8-3. Description of the solution set studied for the Donauzentrum reference building.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Efficient lighting system and controls**	Lighting power density is reduced down to 4.5 W/m² in the common areas and galleries and to 18.1 W/m² in the vending area (shops, midsize stores, food store) because of the installation of LED lamps. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time. Zonal lighting concept reduces ambient lighting, accentuates zones with higher intensity and maintains the perceived brightness impression. The advanced controls is applied in common area and in the shopping area. For the food store and restaurant areas we decreased the value of specific lighting power by around 50% taking constant the operation time during the day.	45% reduction of electricity consumption due to lighting 80% cooling need reduction	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall.
2	**Efficient appliances**	To reduce energy consumption for appliances by improving their efficiency. Appliances is shopping centres consist of : Distribution transformers IT equipment (non-data center) Water Treatment/Distribution PCs(Laptops,Desktops,Monitors) Cash Machines Kitchen equipment(restaurant) Video display/Boards Security systems Vending machine Escalators Elevators Security lighting The appliances can be replaced in maintenance cycles with high efficiency products.	46% in appliance consumption reduction; cooling consumption is reduced by 18%. Considering the whole electricity consumption a reduction by 10%.	The reduction of the internal gain will impact also on temperature inside the building both in winter and summer.

3	**Cooling set point control**	Shops conditioning is individually managed meaning that there is not a common way in ensuring comfort inside the shops. The declared cooling set-point is 25°C but lower temperature can be also registered without taking into consideration the outdoor condition. The main object of this solution is to modulate the cooling setpoint according to the outside temperature in order to prevent big temperature difference between inside and outside that can lead to thermal discomfort to costumers in both summer and mid-season. The control has been studied based on the comfort limit of the adaptive comfort theory in shops areas.	90 % of cooling demand reduction	A better control of indoor temperature during summer and mid-season preventing thermal shock because of high temperature difference between indoor and outdoor.
4	**Natural Ventilation**	Existing skylight windows are used for natural ventilation purpose but without a specific strategy, just manually operated and the operation is based just on the energy manager judgment. The aim is to define a ventilation control strategy in order to automatically operate and control the windows trying to optimize the used of the openable windows already present in the shopping mall.	73% Cooling need reduction in common areas 30% Mechanical ventilation electricity consumption reduction in common areas	The reduced use of air conditioning in common area will promote comfort adaptive strategies.
5	**Photovoltaic plant**	The PV plant can improve the renewable energy produced on-site and decrease the energy imported from the grid. If the PV is combined with a battery energy storage system, advantageous situation are for suppling a dedicated load (e.g. lighting system) or shave the peak (only to smooth the energy profile and not strictly related to the energy prices during the day).	With this solution part of the electric consumption can be covered combined with a self production reducing CO_2 emissions as well.	-
6	**Revolving doors**	The reduction of the infiltration losses can be operated by using revolving doors which contribute to keep an energy efficient building by regulation its temperature and air pressure. Thanks to the design of revolving doors, much less air rushes out when people exit and enter through them.	30% of heating demand reduction 25% of infiltration losses reduction	The impact on thermal comfort is expected especially in the zone adjacent to entrance where the possibilities of cold draughts, especially during winter season are consistently limited.

8.4 Energy savings

The graph in Figure 8-7 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described in par.8.3.

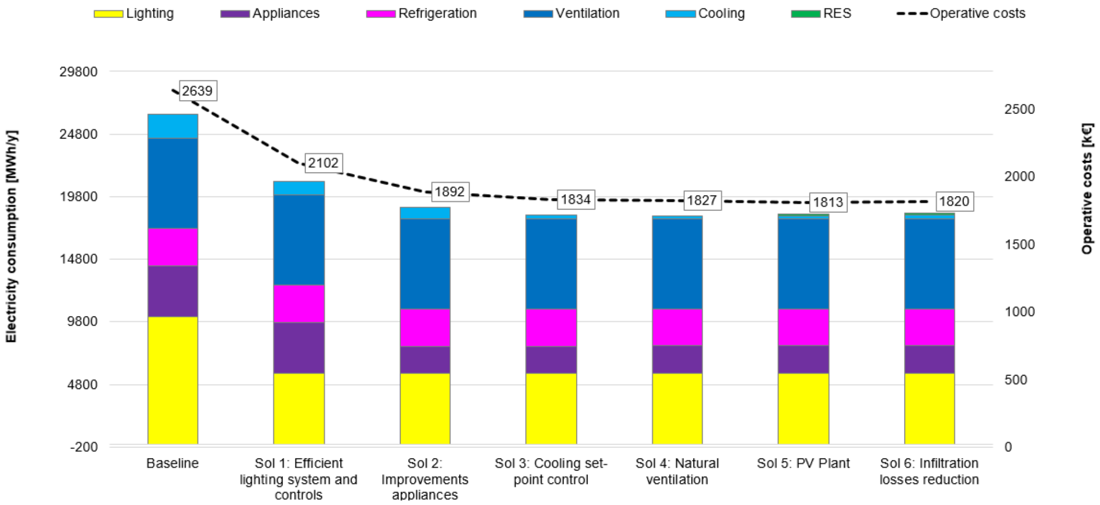

Figure 8-7. Yearly electricity consumption and operative costs.

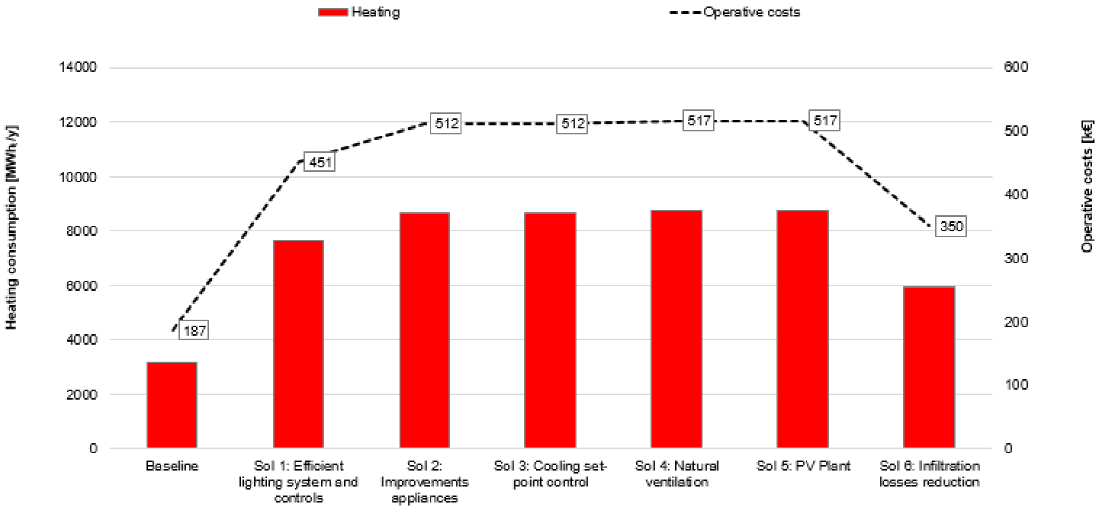

Figure 8-8 Yearly heating consumption and operative costs.

Figure 8-8 shows the yearly heating consumption and its operative costs while the graph in Figure 8-9 shows the total primary energy consumption as well as operative costs. The solution set package analysed leads to a reduction of 26% of primary energy consumption.

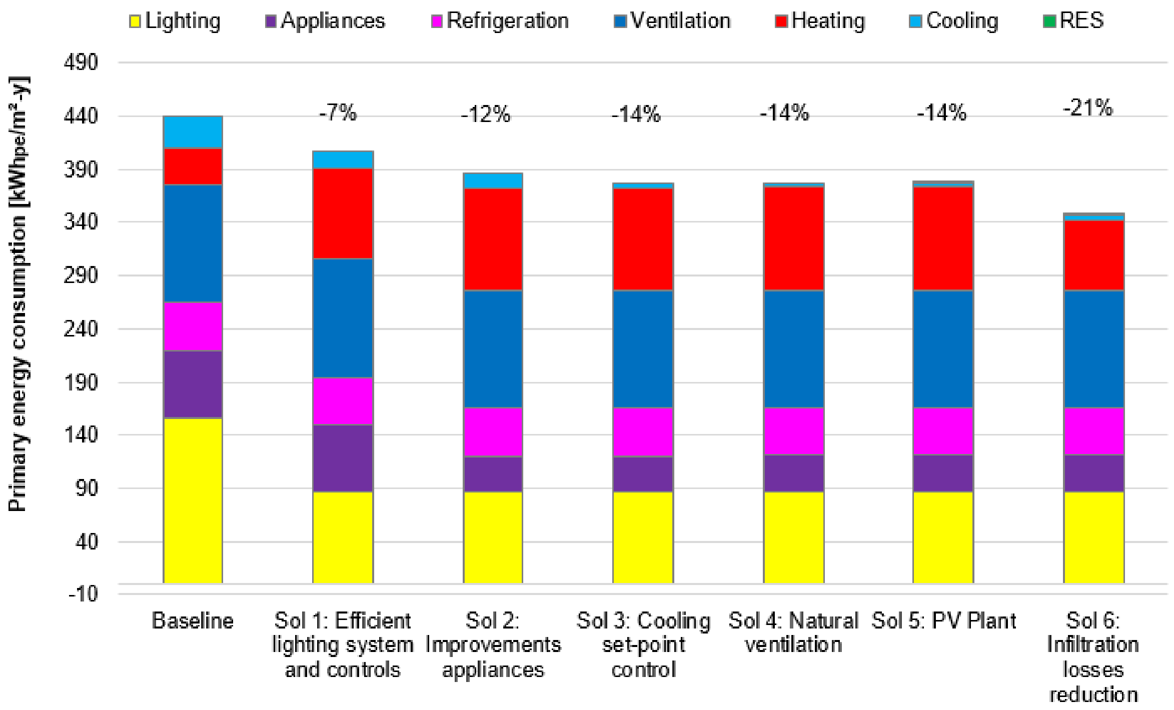

Figure 8-9. Primary energy consumption and total operative costs.

8.5 Economic analysis

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 6,118,889 €. Considering an average cost of electricity of 0.10 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 655,827 €/year.

The results of the cash flows for the whole solution set over the 25 years period studied are shown in Figure 8-10. The estimated Pay Back Time is expected to be between 3.2 (discount factor 0%) and 3.8 years (discount factor 8%) depending on the discount factor which can be applied to the investment.

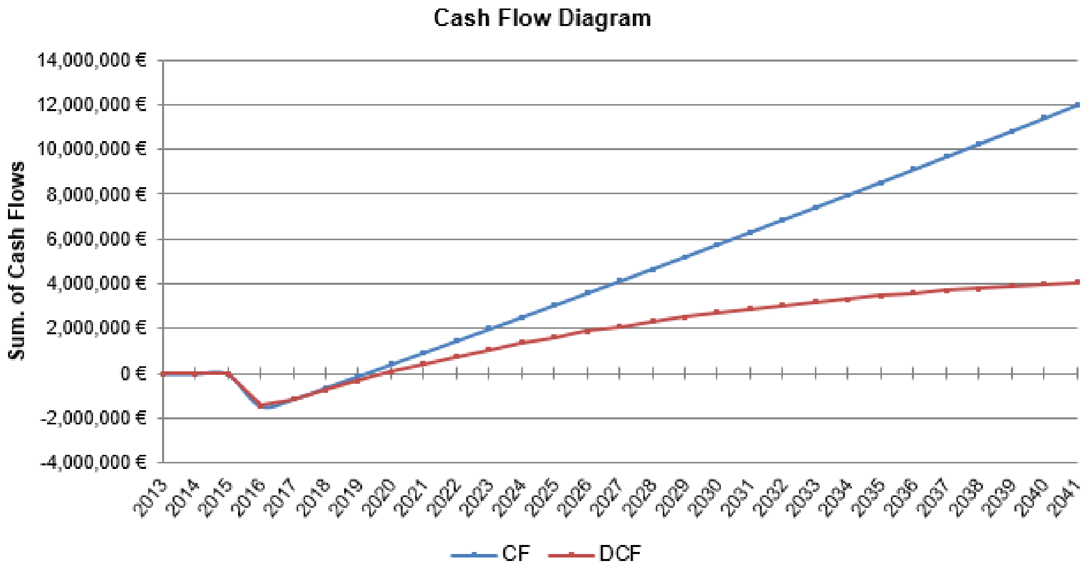

Figure 8-10 Cash flow diagram for solution 1 + 2 + 3+4+5+6 when discount factor is equal to 8%

8.6 Final considerations

The target of 75% of primary energy reduction is very ambitious for the specific case of the Donauzentrum. The management of the shopping centre is investing regularly on sustainable solutions for the shopping centre. Considering this aspect, we tailor-made the study considering both solutions planned by the energy retrofit plan of the shopping mall such as new efficient lighting and control and the natural ventilation exploitation in common areas, and suggestion on other solution that can be beneficial in terms of operating costs and payback.

The solution-set proposed includes:

- Solution 1: Efficient lighting system and controls
- Solution 2: Appliance energy consumption improvements
- Solution 3: Cooling set point control
- Solution 4: Natural ventilation exploitation in common areas
- Solution 5: Photovoltaic plant
- Solution 6: Revolving doors

The solution set package proposed can lead to a reduction of **26%** of primary energy consumption. Considering the expected investment cost related to each solution, a total investment cost of around **6,118,889 €** is estimated (incl. tax) for the implementation of the solution set.

With an average cost of electricity of **0.10 €/kWh** and **0.059 €/kWh** for the district heating, the energy savings due to energy conservation and efficiency measures are foreseen to be around **750,000 €** in the first year of operation after retrofit.

The estimated Pay Back Time for this solution-set is expected to be between **3.2 and 3.8 year** with a discount factor range of 0-8%.

9 Pamarys (Silute - Lithuania)

The Pamarys shopping centre was opened in 2004. With a total area of 6,020 m², it offers various facilities: a food store, a centre for decoration, construction materials and household items, a bowling/billiard club, a pharmacy, an optician and a gardening store. Pamarys is well situated, close to two residential areas but it also attracts customers from other parts of the city.

Figure 9-1. Pamarys shopping center (left) and building energy model (right).

9.1 Technological active-installation check-up

Energy demand for space heating and hot water is supplied by the furniture factory heating power plant which is close to the shopping centre.

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating setpoint

No information about the HVAC and refrigeration plant layout of the supermarket are available.

Heating and cooling

It has been assumed no cooling needs. Almost constant electrical profile during the whole year with a little increase in summer (could be for the ventilation) and external temperatures are below 26ºC during almost the whole year.

Ventilation:

To maintain the temperatures within comfort ranges in summer it has been assumed that ventilation works in free cooling mode from middle of May to middle of September. The schedule is from 00:00 to 8:00, with 6 renovations/hour. During the opening time has been also increased the ventilation values at four times.

During heating season, ventilation works in heat recovery mode with an efficiency of 72%, derived from model calibration.

9.2 Analysis of energy consumption. Baseline simulation.

The graph in Figure 9-2 represents the electricity consumption divided by zone function. All the electricity consumption is due to lighting, ventilation and auxiliaries, not influencing the cooling (assuming no cooling needs) and heating (district heating).

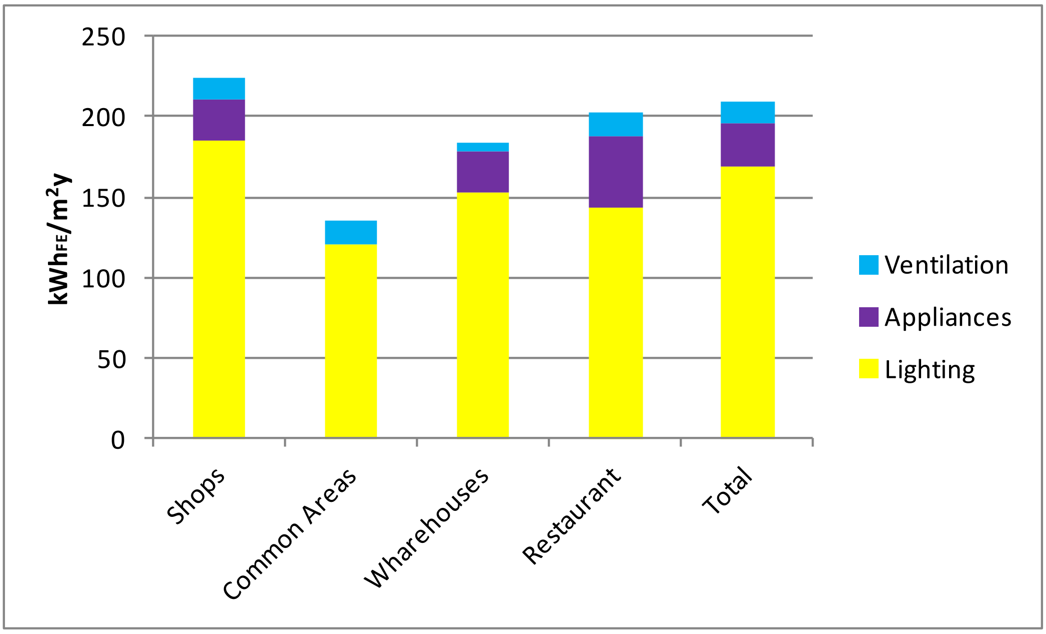

Figure 9-2. Electricity consumption for each group of zones: Common Areas (CMA), Shops (SHP), Warehouses (WRH), Restaurant (RST)

The graph in Figure 9-3 compares the measured electricity consumption in 2013 with the predicted electricity consumption by the simulation model.

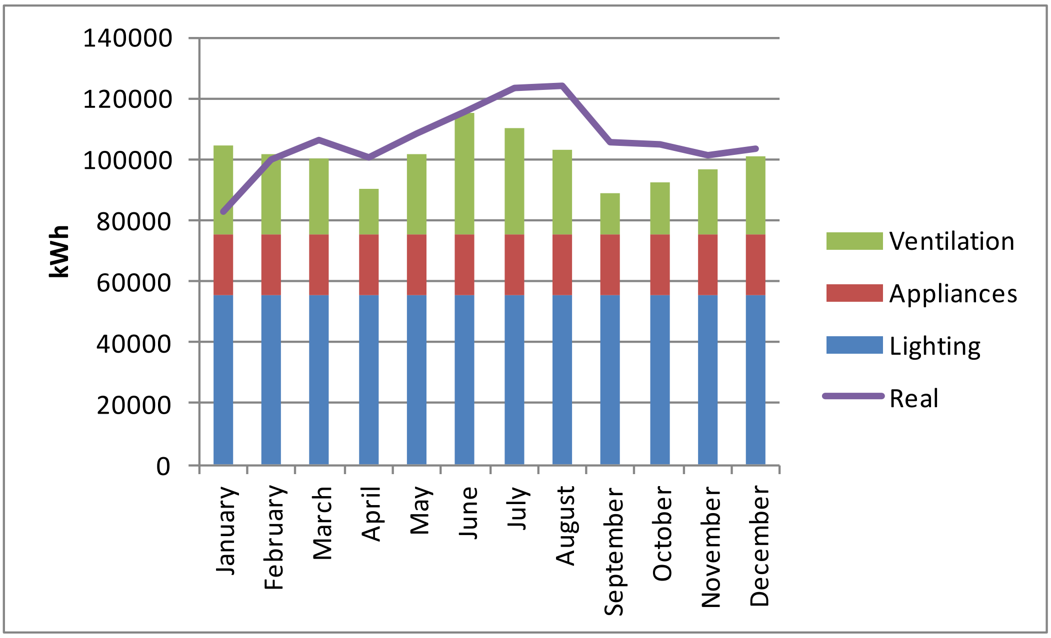

Figure 9-3. Measured and predicted electricity consumption.

The graph in Figure 9-4 shows the comparison between the actual DHW and heating demand in 2013 and the predicted one. DWH demand has been derived from the heating consumption during summer and assumed as constant over the whole year.

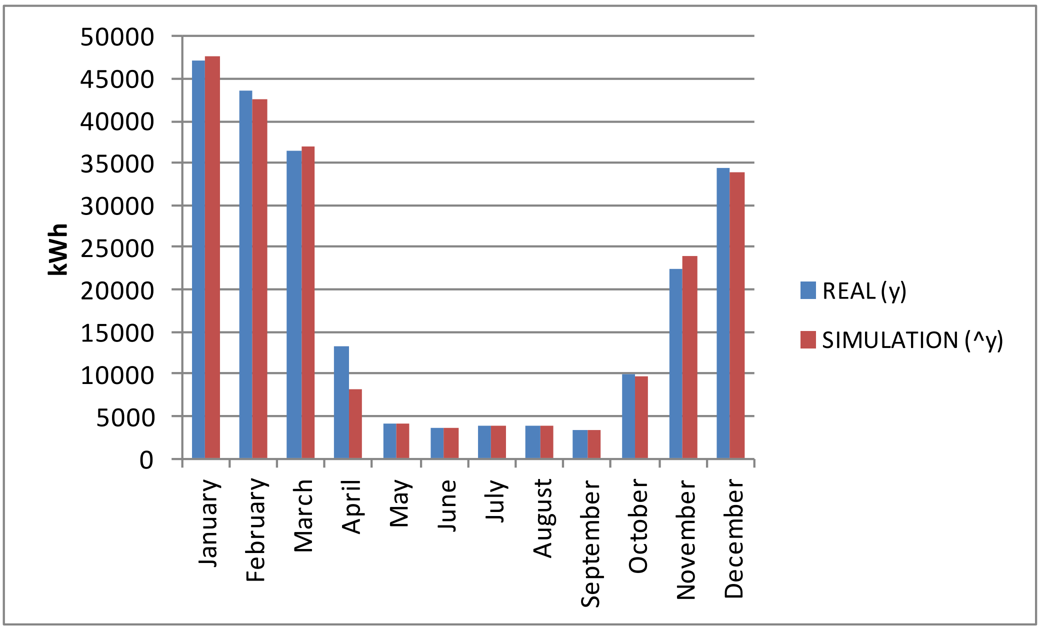

Figure 9-4. Comparison between real data consumption for heating in 2013 and simulation results.

9.3 Selection of suitable solutions

This particular building has no cooling needs, therefore all the energy efficient measures has been studied for reducing the heating consumption. The measures proposed are easily replicable in other shopping centres in heating dominated climate. The replication potential is, therefore, limited to the reduction of heating demand (apart from the RES system). In this building, the solution-set identified achieves 63% of primary energy reduction with 6.29 years of payback. This solution-set would only be interesting for location with favourable conditions for the PV installation. Table 9-1 reports a description of the solution set proposed for the Pamarys reference building.

Table 9-1. Description of the solution set studied for the Pamarys reference building.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Effective artificial lighting equipment + control strategies**	To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off With this solution is possible to reduce the electricity consumption of the building. Four different cases have been studied: Case 1: Intermediate energy efficient lighting with no control. Case 2: Advanced energy efficient lighting with no control. Case 3: Advanced energy efficient lighting with control for operation hours. Case 4: Advanced energy efficient lighting with control for operation hours and night milieu. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.	Case 1: 12% reduction in lighting consumption. Case 2: 37% reduction in lighting consumption. Case 3: 58% reduction in lighting consumption. Case 4: More than 60% reduction in lighting consumption.	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping centre.
2	**Building envelope thermal improvement** **Heat recovery** **Heating set point management**	Improvements in the envelope: After a parametric analysis of the insulation: Walls from 5 cm (baseline) to 15 cm (final solution). Roof: from 10 cm (baseline) to 20 cm (final solution). Floor: from 7 cm (baseline) to 20 cm (final solution). Heat recovery: Increase in 5%. Variation of heating set point: Change the heating set point from 20ºC to 19ºC.	Reduction in more than 40% of heating demand in case of application together with Solution 1.	Improve the comfort during the occupied hours. Softening discomfort due to overheating especially in summer and mid-season period
3	**RES integration:** **3a. PV panels** **3b. Wind turbine**	Silute location has suitable weather conditions for the exploitation of RES. A total roof surface of 1,500 m² is available on the roof for PV installation. The photovoltaic generation profile can potentially reduce peak demand since photovoltaic generation peaks coincide with the market demand peaks. It is possible also to install a medium-size (150 kW) wind turbine system, due to the climatologic conditions (wind speed ~ 5 – 6 m/s) and without buildings surrounding the shopping mall.	Predicted energy generation: Wind Power: 82,738 kWh/y Photovoltaic: 156,393 kWh/y	-

9.4 Energy savings

The graph in Figure 9-5 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described in par. 9.3.

The solution set package analysed leads to a reduction of 60% of energy consumption. Thanks to the wind power we can increase to 67%, but as can be seen in Annex I in the Pamarys report this solution lead to a ROI above 7 years (out of the scope of the project).

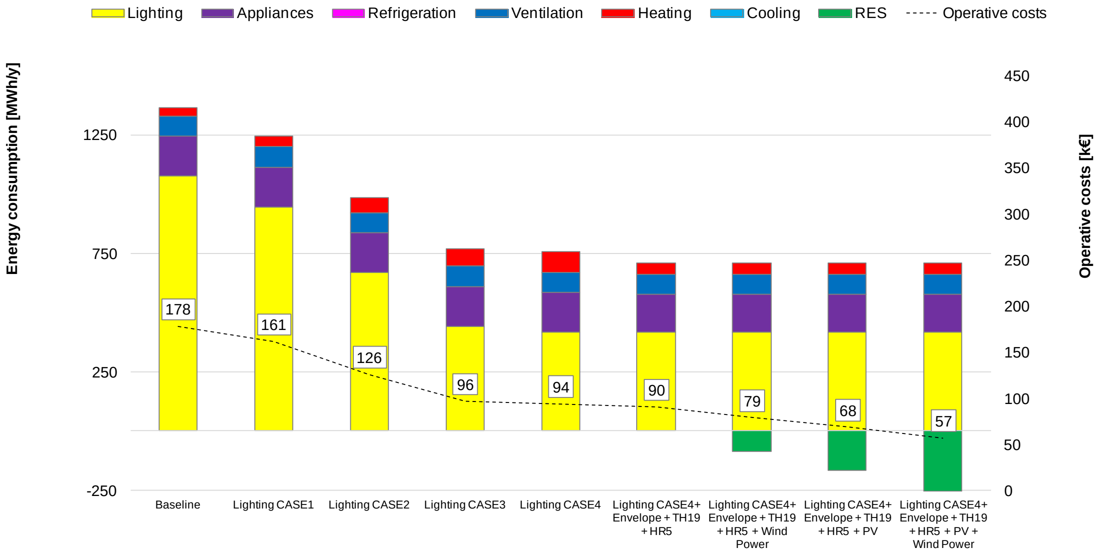

Figure 9-5. Yearly final energy consumption

The graph in Figure 9-6 shows the actual yearly primary energy consumption of the baseline model and the potential primary energy savings of the energy efficiency measures described in paragraph 9.3, considering a primary energy factor of 2.723 kWh_{pe}/kWh_{el} for the electricity and 0.112 kWh_{pe}/kWh_{el} for the heating (biomass district heating).

The solution set package analysed leads to a reduction of 63% of primary energy consumption. Thanks to the wind power we can increase to 69%, but as can be seen in Annex I in the Pamarys report this solution lead to a ROI above 7 years (out of the scope of the project).

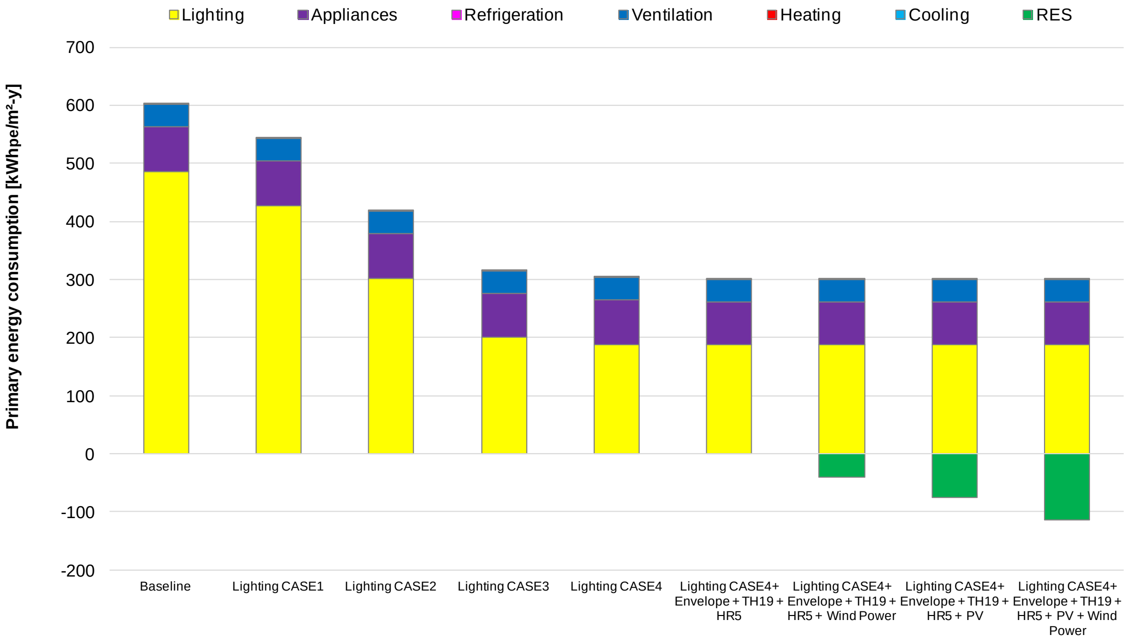

Figure 9-6. Yearly primary energy consumption.

9.5 Economic analysis

The installation of efficient lighting (LED) with better control strategy, addition of energy efficiency measures and PV would have a cost of 506,000 € with a payback time of 6.29 years.

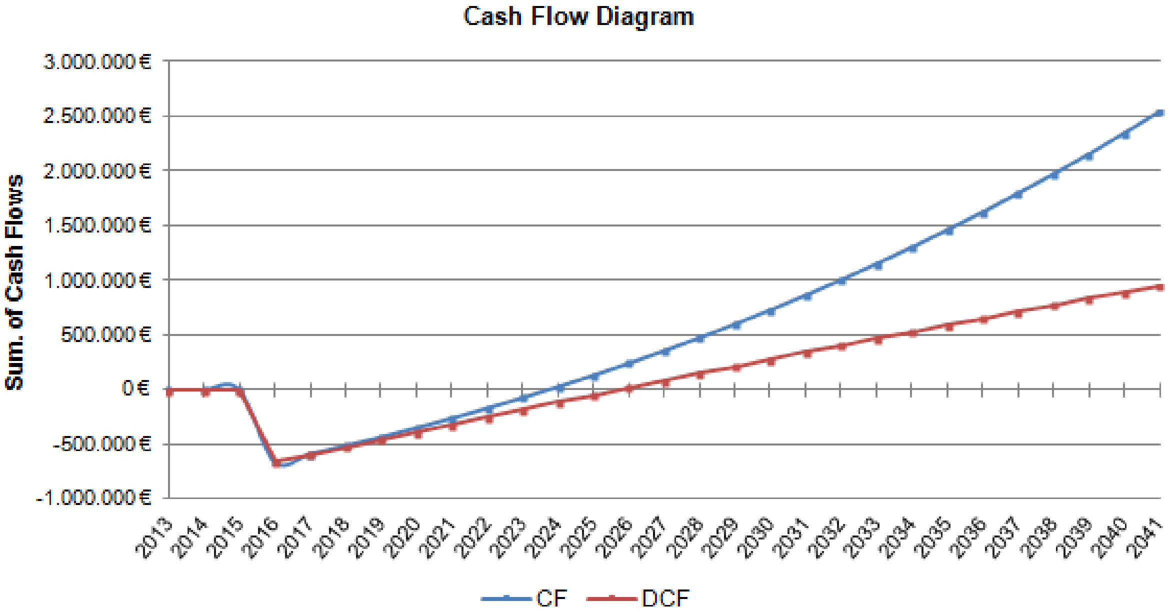

Figure 9-7 Cash flow diagram of the solution set (solution 1+2+3a).

9.6 Final considerations

After developing several simulations implementing both passive solutions (energy efficiency measures) and active solutions (artificial lighting and RES), we have obtained the conclusion that could have a great potential of improvement above 60% of energy reduction. With the energy efficiency measures here described, it would be possible to reduce around 40% the heating demand of the building and thus the expenses due to the district heating. With the advanced artificial lighting systems it is possible to reduce until 60% of the lighting electrical consumption and thus reduce the electricity bill. With the RES it is possible to cover part of the electricity demand of the building and in this way to reduce the electricity coming from the grid.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decided to reduce lighting power density (solution 1). This solution with an investment of 92,000 € offered almost 49% of primary energy savings. The implementation of solution 1 would have a PBT of less than 1 year.

Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need, but increasing the heating demand. Therefore, a complete retrofit with insulation layer, heat recovery and management of heating set-point (solution 2) is suggested in order to reduce the heating need. This solution with an investment of around 243,000 €, joined with the previous solution, offered 50% of primary energy savings for the building. The implementation of solution 2 (measures 1b+2) would have a payback of 3.89 years.

Finally, the installation of a PV system or a wind turbine will increase the self-consumption and self-production, and decrease the energy imported from the grid and the CO_2 emissions. In Pamarys, it would be feasible to install PV systems on the roof and wind turbines (solutions 3a and 3b). Firstly, the study of PV system with an estimated investment of near 171,000 € (1,500 m^2), joined with the previous solutions, offered 63% of primary energy savings. The implementation of solution 3a would have a payback of 6.29 years. If we introduce wind power in order to exploit more the local generation (solution 3b), the study concluded that, with an estimated investment of 450,000 € for a 150 kW wind turbine, joined with the previous solutions, offered 69% of primary energy savings. The addition of solution 3b would have a payback of 24 years. Since the objective was to work with ROIs less than 7 years, we discarded this solution.

10 Studlendas (Klaipeda - Lithuania)

Studlendas is a bright and modern shopping centre, which opened in 2006. It is located near the Klaipeda University campus, a highly frequented area. It offers more than 50 retail units on two floors. This is the first project in Lithuania which combines both private and public segments. Its area of 12,637 m² includes banking services, a pharmacy, repair shops, a bowling and fitness centre and household stores. The centre owner is continuously working on improving the building's energy and its technical equipment.

Figure 10-1. Studlendas shopping centre (left), satellite view (centre) and building simulation model (right).

10.1 Technological active-installation check-up

Energy demand for space heating and hot water is supplied by a district heating power plant which is next to the shopping centre.

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time.

No information about the HVAC and refrigeration plant layout of the supermarket are available.

Heating and cooling

It has been assumed no cooling needs. Almost constant electrical profile during the whole year with a little increase in summer (could be for the ventilation) and external temperatures are below 26ºC during almost the whole year.

Ventilation

To maintain the temperatures in summer it has been assumed free cooling from middle of May to middle of September. The schedule is from 00:00 to 8:00, with 8 ach. During the opening period has been also increased the ventilation values to 4.

It has been assumed a heat recovery from middle of September to middle of May, with an efficiency of 55%.

10.2 Analysis of energy consumption. Baseline simulation.

The graph in Figure 10-2 represents the electricity consumption divided by zone function. All the electricity consumption is due to lighting, ventilation and auxiliaries, not influencing the cooling (assuming no cooling needs) and heating (district heating).

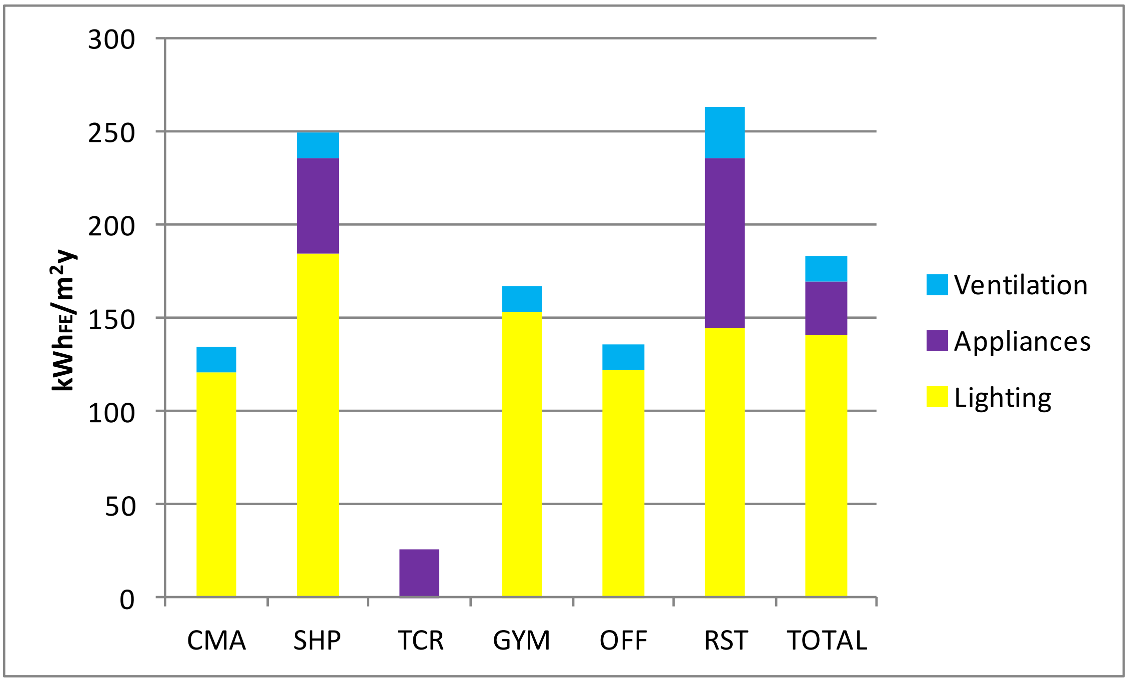

Figure 10-2. Electricity consumption for each group of zones: Common Areas (CMA), Shops (SHP), Technical room (TCR), Gymnasium (GYM), Offices (OFF), Restaurant (RST)

The graph in Figure 10-3 compares the measured electricity consumption in 2013 with the predicted electricity consumption.

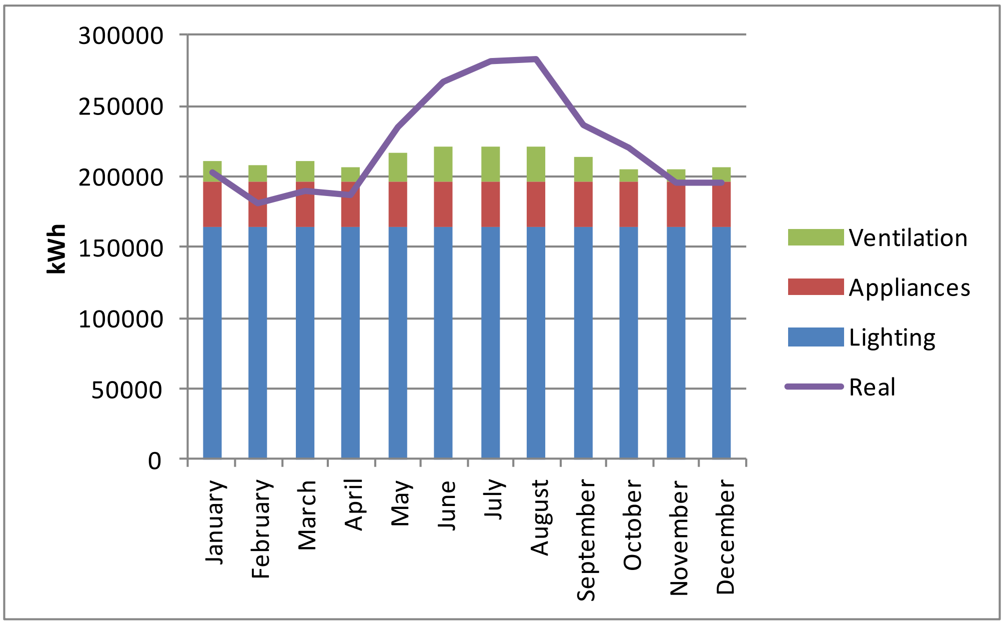

Figure 10-3. Measured and predicted electricity consumption.

The graph in Figure 10-4 compares the measured heating consumption in 2013 with simulation results. DWH demand has been derived from the heating consumption during summer and assumed as constant over the whole year.

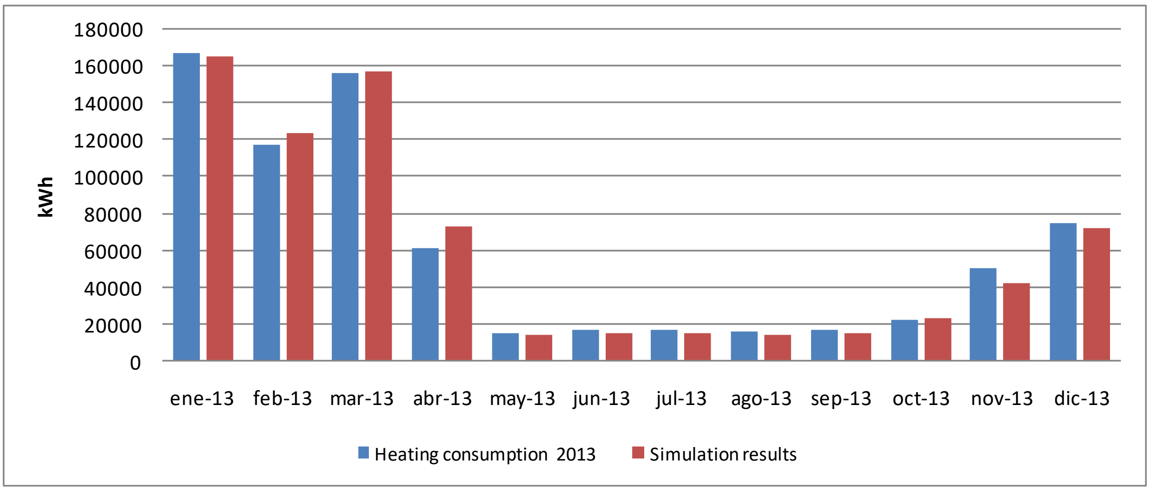

Figure 10-4. Measured and predicted heating demand.

10.3 Selection of suitable solutions

This shopping centre presents similar behaviour than the previous one (Pamarys) and it has been assumed that there are no cooling needs (no information), therefore all the energy efficient measures have the objective to reduce the heating demand. As stated for the Pamarys shopping centre, the measures proposed are easily replicable in other shopping centres in heating dominated climate. In this building, the solution-set identified achieves 50% of primary energy reduction with 5.72 years of payback. Table 10-1 reports a description of the solution set proposed for the Studlendas reference building.

Table 10-1. Description of the solution set studied for the Studlendas reference building.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Effective artificial lighting equipment + control strategies**	To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off With this solution is possible to reduce the electricity consumption of the building. Four different cases have been studied: Case 1: Intermediate energy efficient lighting with no control. Case 2: Advanced energy efficient lighting with no control. Case 3: Advanced energy efficient lighting with control for operation hours. Case 4: Advanced energy efficient lighting with control for operation hours and night milieu. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.	Case 1: 20% reduction in lighting consumption. Case 2: 40% reduction in lighting consumption. Case 3: 60% reduction in lighting consumption. Case 4: More than 60% reduction in lighting consumption.	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping centre.
2	**Building envelope thermal improvement** **Heat recovery** **Heating set point management·** **Shadings for solar control the south façade**	Improvements in the envelope: After a parametric analysis of the insulation: Walls: from 25 cm (baseline) to 30 cm (final solution). Roof: from 21 cm (baseline) to 9 cm (final solution). Floor: from 5 cm (baseline) to 15 cm (final solution). Variation of heating set point: Change the heating set point from 21ºC to 19ºC. Shadings on the south façade glazing: Change from 0% to 60% the shading factor.	Reduction in more than 40% of heating demand in case of application together with Solution 1.	Improve the comfort during the occupied hours. Softening discomfort due to overheating especially in summer and mid-season period
3	**RES integration:** **3a. PV panels** **3b. Wind turbine**	Klaipeda location has suitable weather conditions for the exploitation of RES. A total roof surface of 3,000 m² is available on the roof for PV installation.	Predicted energy generation: Wind Power: 94,000 kWh/y Photovoltaic: 315,374 kWh/y	-

		The photovoltaic generation profile is suitable for the demand profile of the building because the photovoltaic generation peaks coincide with the market demand peaks. It is possible to install a medium-size (150 kW) wind turbine system, due to the climatologic conditions (wind speed ~ 5 – 6 m/s) and without buildings surrounding the shopping mall.		

10.4 Energy savings

The graph in Figure 10-5 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described in paragraph 10.3.

The solution set package analysed leads to a reduction of 45% of energy consumption. Thanks to the RES (PV + wind power) we can increase to 62%, but as can be seen in Annex I in the Studlendas report this solution lead to a ROI above 7 years (out of the scope of the project).

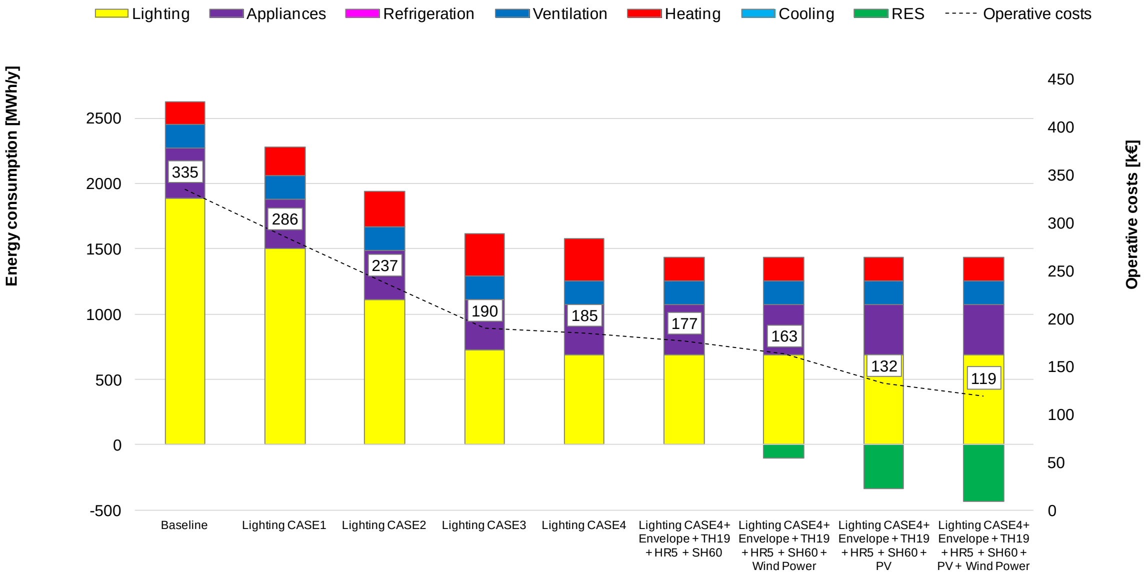

Figure 10-5. Yearly final energy consumption.

The graph in Figure 10-6 shows the actual yearly primary energy consumption of the baseline model and the potential primary energy savings of the energy efficiency measures described in paragraph 10.3, considering a primary energy factor of 2.723 kWh_{pe}/kWh_{el} for the electricity and 0.112 kWh_{pe}/kWh_{el} for the heating (biomass district heating).

The solution set package analysed leads to a reduction of 50% of primary energy consumption. Thanks to the RES (PV + wind power) we can increase to 66%, but as can be seen in Annex I in the Studlendas report this solution lead to a ROI above 7 years (out of the scope of the project).

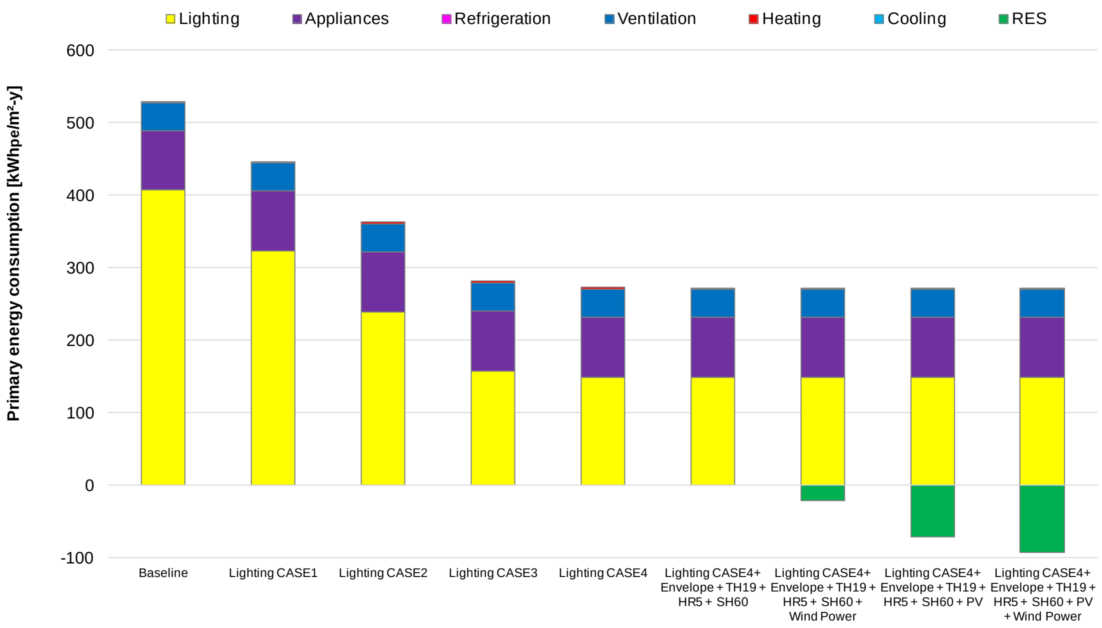

Figure 10-6. Yearly primary energy consumption.

10.5 Economic analysis

The installation of efficient lighting (LED) with better control strategy, addition of energy efficiency measures would have a cost of 470,400 € with a payback time of 5.72 years.

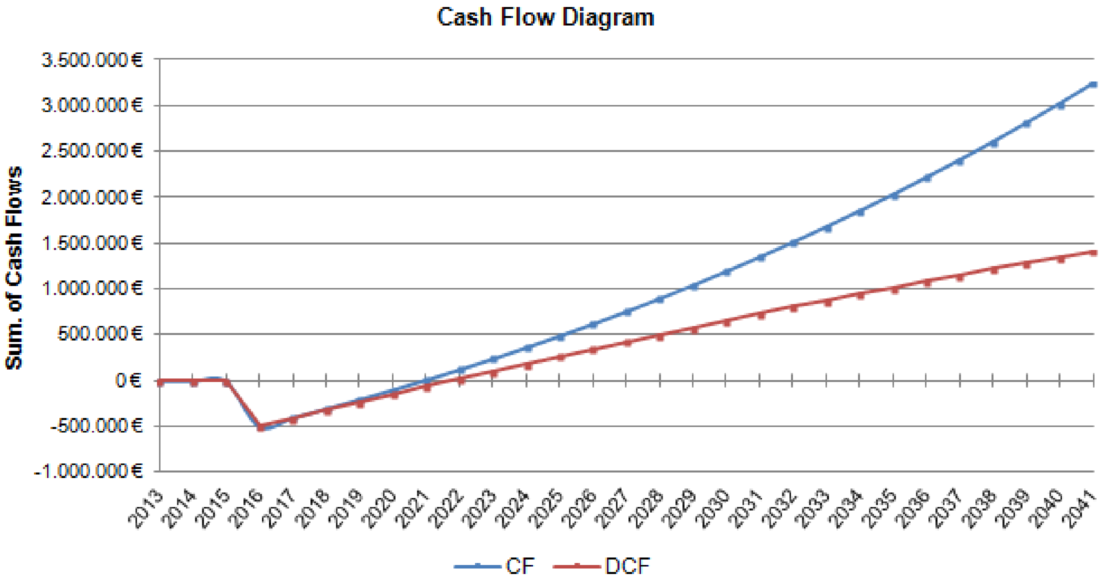

Figure 10-7. Cash flow diagram

10.6 Final considerations

After developing several simulations implementing both passive solutions (energy efficiency measures) and active solutions (artificial lighting and RES), we have obtained the conclusion that could have a great potential of improvement of around 50% of primary energy reduction. With the energy efficiency measures here described, it would be possible to reduce 40% the heating demand of the building and thus the expenses due to the district heating. With the advanced artificial lighting systems it is possible to reduce 60% the lighting electrical consumption and thus reduce the electricity bill. With the RES it is possible to cover part of the electricity demand of the building and in this way to reduce the electricity coming from the grid.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decided to reduce lighting power density **(solution 1)**. This solution with an investment of 184,000 € offered almost 49% of primary energy savings, with a payback time of 1.83 years. Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need, but increasing the heating demand. Therefore, a complete retrofit with insulation layer, heat recovery, variation of heating set-point and shadings on the south façade (**solution 2**) is suggested in order to lower back heating need. This solution with an investment of around 286,400 €, joined with the previous solution, offered 50% of primary energy savings for the building. The implementation of solution 2 (measures 1b+2) would have a payback time of 5.72 years.

Finally, the installation of a PV system or a wind turbine will increase the self-consumption and self-production, and decrease the energy imported from the grid and the CO_2 emissions. In the Studlendas case, it would be feasible to install PV systems on the roof and wind turbines (solutions 3a and 3b). Firstly, the study of PV system with an estimated investment of near 344,000 € (3,000 m^2), joined with the previous solutions, offered 62% of primary energy savings. The implementation of solution 3a would have a payback of 11 years. If we introduce wind power instead of PV in order to exploit other local generation solutions (solution 3b), with an estimated investment of 450,000 € for a 150 kW wind turbine, joined with the previous solutions, we would have 53% of primary energy savings. The addition of solution 3b would have a PBT of 22 years. Since the objective was to work with ROIs less than 7 years, these two last solutions were discarded.

11 Waasland (Sint-Niklaas - Belgium)

Located in Sint-Niklaas (Figure 11-1), the original building dates from 1972. In January 2003 to March 2004 it was submitted to a retrofitting actuation in the actually called “South Gallery”, including an extension with a whole new section. Actually Waasland shopping centre includes 140 stores on 45,600 m² of retail space with 6.3 million visitors per year.

Figure 11-1. Satellite view of Waasland shopping centre

Figure 11-2. Bird’s eye view of Waasland shopping centre (left) and main entrance facade (right).

Waasland shopping center (Figure 11-2) has a total external dimension of 215 m (width), 275 m (length) and 8 m (height). The height inside the shops is 7 m (+1 m buffer), and in the common areas with light dooms are 14 m high. The longer building axis is rotated of 30° from absolute north.

11.1 Technological active-installation check-up

In the building, two gas boilers with 1400 kW_{th} (generally only one is working) and 10 air-to-water heat pumps are installed. Heat pumps use air to dissipate heat/cool energy, and water to distribute the energy (heat/cool). There is not any heat recovery system.

We considered the following efficiencies to estimate the electricity consumption:

- Gas boiler eff: 0.9
- Air-to-water heat pump EER: 2.5

The heating demand of the mall has been calculated by imposing a set point temperature of 20°C from 7 am to 9 pm being disconnected during night. The cooling demand has been calculated by imposing a set point temperature of 23°C from 7 am to 9 pm. The cooling system is turned off during the night. No additional air humidification is considered during the winter time.

The heating and cooling system are shut off on Sunday and closing days.

11.2 Analysis of energy consumption. Baseline simulation.

The graph in Figure 11-3 represents the electricity consumption in the common area. It can be seen that the highest electricity consumption is due to the high lighting power density.

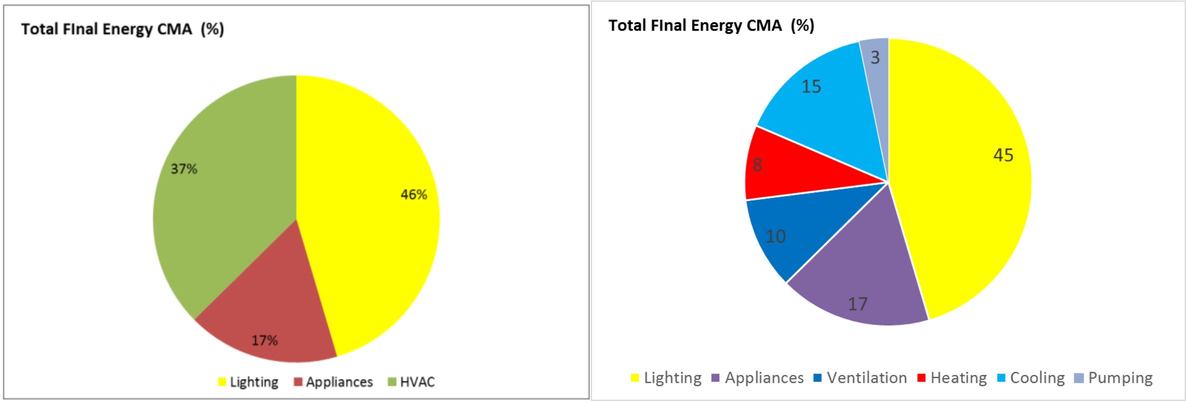

Figure 11-3. Electricity consumption percentage for Common Areas (CMA).

Total electricity consumption simulated for the common areas amounts at 2,334 MWh/y which corresponds to 294 kWh/m^2-y considering the conditioned area of 7,934 m^2.

Considering the whole shopping mall (Figure 11-4), the results are proportionally similar.

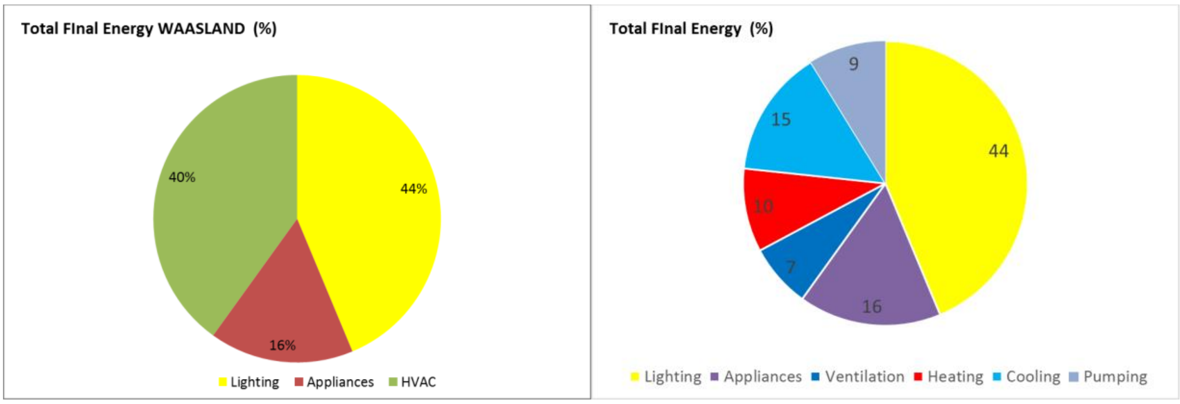

Figure 11-4. Electricity consumption percentage for the whole shopping mall

The graphs in Figure 11-5 and Figure 11-6 compare predicted (by the calibrated model) and measured electricity and gas consumption.

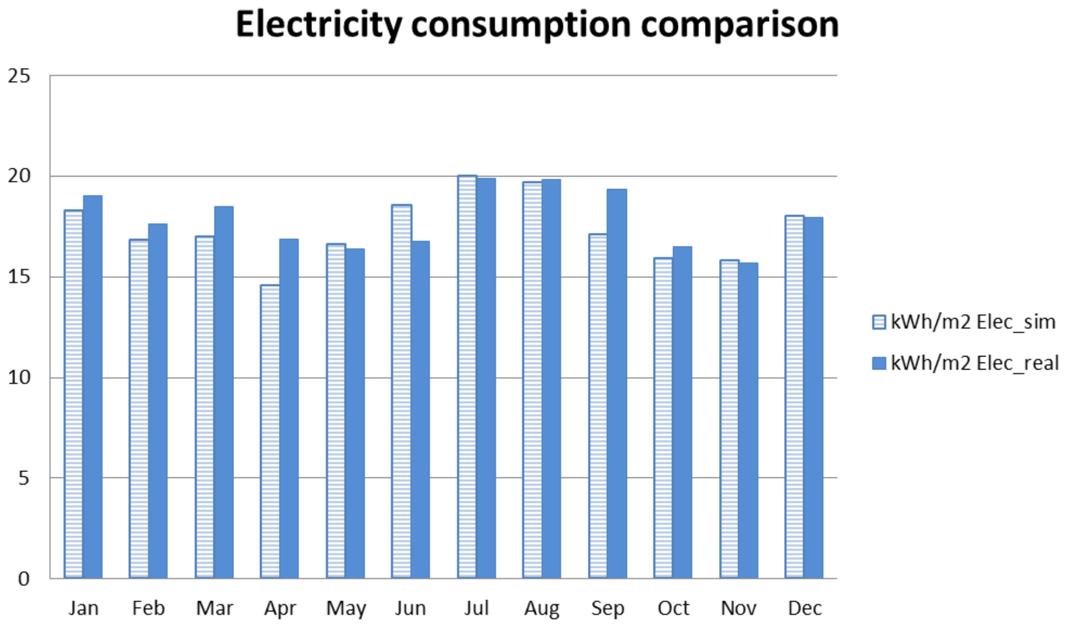

Figure 11-5. Predicted and measured monthly electricity consumption (year 2015).

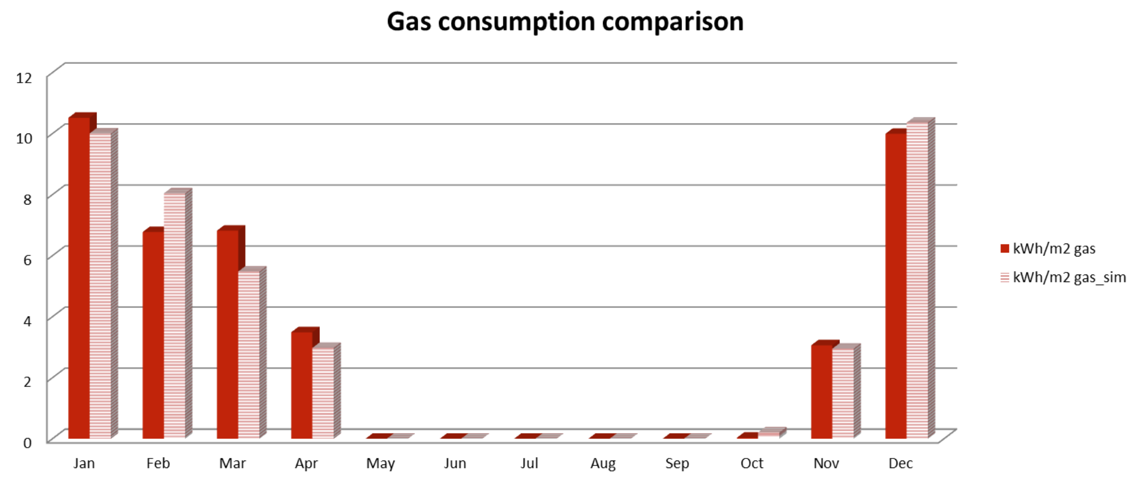

Figure 11-6. Predicted and measured monthly gas consumption (year 2015).

11.3 Selection of suitable solutions

Waasland shopping centre is a big shopping centre (45,000 m² of retail space) with only one floor. Therefore, there is an important area available for installation of renewable energy source (such as PV panels). However, parking is located on the roof. Therefore, the most suitable solution would be to install PV on parking canopies which will also work as shading system (it would be necessary to pay attention to the total weight). All the individual measures proposed have high replication potential in shopping centres in both heating and cooling dominated climates. However, depending on the combination of the different solutions forming a solution-set, different options could be proposed, for different type of shopping centres (for instance, the improvement of insulation and heat recovery would be suitable for heating dominated buildings, whilst efficient lighting and vegetable wall would be applied for reducing the cooling needs mainly). Therefore, after the study, two solution-sets were proposed for Waasland shopping centre:

Table 11-1. Solution set 1 for Waasland reference building.

Solutions		measures
1	**Lighting**	LED installation and new control strategy
2	**Green integration**	SE external green walls
3	**Appliances**	Energy efficient appliances, escalators etc.
4	**Heat recovery**	Heat recovery equipment integration
5	**RES – PV**	Photovoltaic panels on the ground

Table 11-2. Solution set 2 for Waasland reference building.

Solutions		measures
1	**Lighting**	LED installation and new control strategy
2	**Green integration**	SE external green walls
3	**Appliances**	Energy efficient appliances, escalators etc.
4	**RES – PV**	Photovoltaic panels on the ground
5	**RES – PV + Batteries**	Photovoltaic panels on the ground + Electrical storage

Table 11-3 reports a description of the individual solutions proposed for the Waasland reference building.

Table 11-3. Description of the solution set studied for the Waasland reference building.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Efficient lighting and control**	Lighting power density is reduced down to 10 W/m² in the common areas and galleries and to 70% in the other areas (shops, restaurants, food store) because of the installation of LED lamps. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.	55% reduction of electricity consumption due to lighting 85% cooling need reduction	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall.
3	**Green integration**	Exterior wall covered with climbing vegetation (foliage fixed with wiring). 1576 m² of vegetation on the South-East external walls (possible extension to walls facing East and West). A plant layer added to the facade can improve its effective thermal resistance by 0.0 – 0.7 m²K/W, depending on a range of inputs for wall parameters, climate zones, and plant characteristics (particularly leaf area index).	Small energy savings during summer conditions by solar shading and thermal energy savings by reduced air infiltration rates because of the vegetation. (1% of cooling energy demand; optionally up to 2,5%, when E and W walls will be covered with foliage)	Improve of thermal comfort inside the building and “green” visual impact. Improvement of microclimate in the neighbourhood of shopping centre building by humidity and dust PMs. Improved rainfall water management.
4	**Appliances replacement**	It is assumed a reduction of 50% of the energy consumption ratios used as baseline by replacing existing appliances in more efficient ones.	4% electricity consumption	The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.
5	**Heat recovery**	Integration of heat recovery system to the existing installations with 50% of efficiency,	25% reduction of heating consumption (final energy) by the thermal installation. Thermal demand of the building will be the same, however, with heat recovery	-

Solutions		Description	Expected energy savings	Expected impact on comfort
			system the final consumption will be lower.	
6.1	**RES – PV**	The only PV plant can improve the “green-energy” produced on-site and decrease the energy imported from the grid. 4,600 m² of polichristaline PV panels have been used for the study with a local generation potential coverage of 50% (focused on lighting and appliances electricity consumption).	With this solution part of the electrical consumption can be covered combined with a self electricity production with enclosed CO2 emissions reduction (35% of demand coverage by RES with 4600 m² of panels used.)	-
6.2	**RES – PV + Batteries**	The only PV plant can improve the “green-energy” produced on-site and decrease the energy imported from the grid. If the PV is combined with a battery energy storage system, advantageous situation are for suppling a dedicated load (e.g. lighting system) or shave the peak (only to smooth the energy profile and not strictly related to the energy prices during the day). 4600 m² of polichristaline PV panels and a set of electrical storage batteries (with 500 kW of capacity and 2000 kWh of energy storage) have been used for the calculation with a local generation potential coverage of 50% (focused on lighting and appliances electricity consumption).	With this solution part of the electrical consumption can be covered combined with a self electricity production with enclosed CO2 emissions reduction (46% of demand coverage by RES with 4600 m² PV panels and 2000 kWh of electrical storage.)	-

11.4 Energy savings

The graph in Figure 11-7 shows the actual yearly primary energy consumption of the baseline model for the overall shopping mall and the potential energy savings of the energy efficiency measures described in par. 11.3. for the two solution-sets proposed.

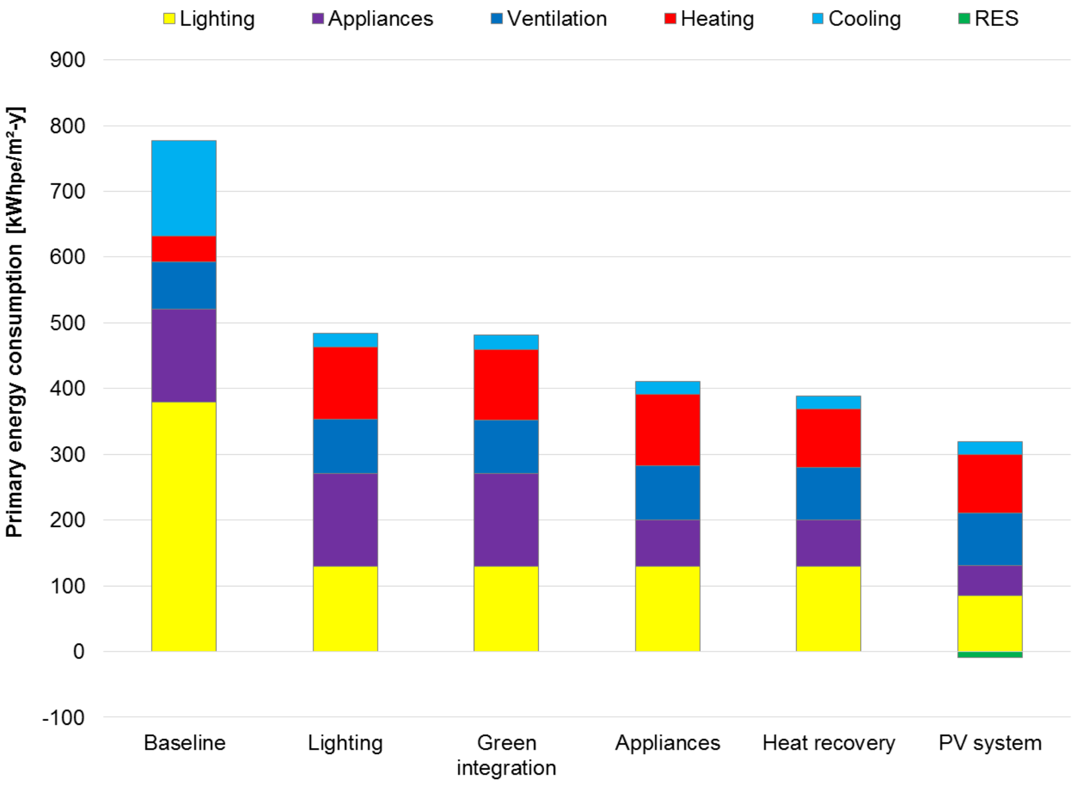

Figure 11-7. Yearly primary energy consumption in Waasland shopping centre. Solution-set 1.

The graph in Figure 11-8 the actual yearly final energy consumption of the baseline model for the overall building and the potential energy savings of the energy efficiency measures described. Total costs refers to the operative costs due to the price of electricity, gas or biomass.

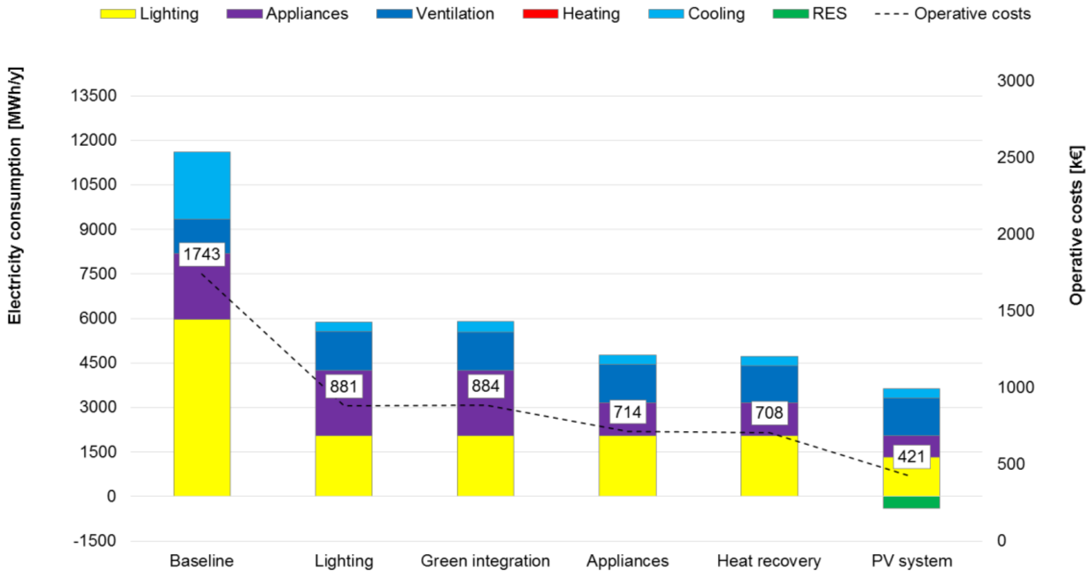

Figure 11-8. Yearly Electricity consumption and operative costs in WSc. Solution –set 1.

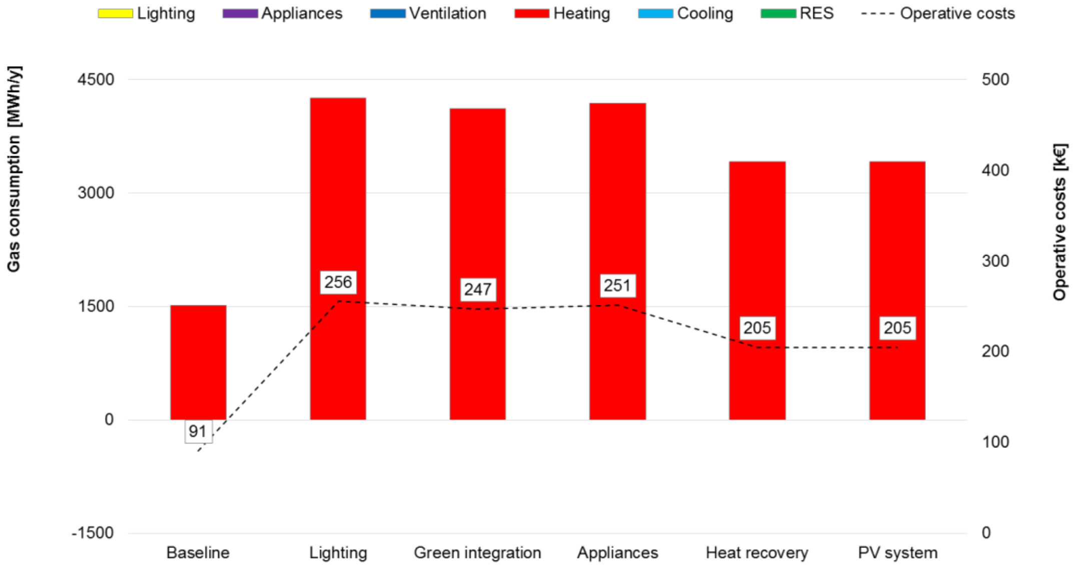

Figure 11-9. Yearly Gas consumption and operative costs in WSc. Solution – set 1.

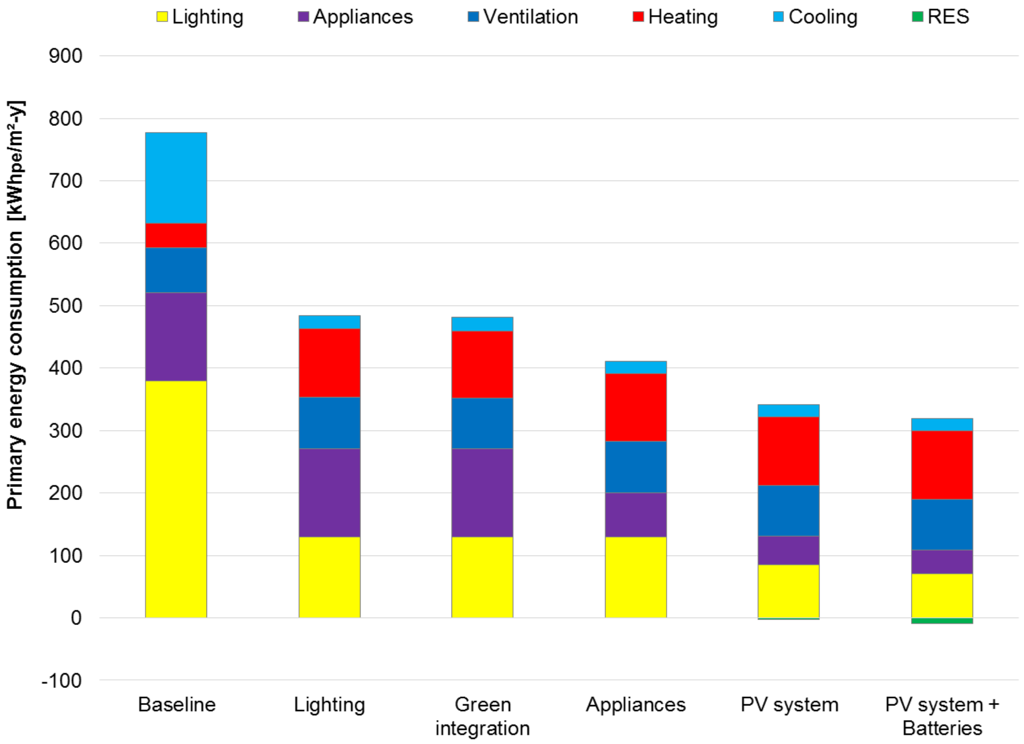

Figure 11-10. Yearly primary energy consumption in Waasland shopping centre. Solution-set 2.

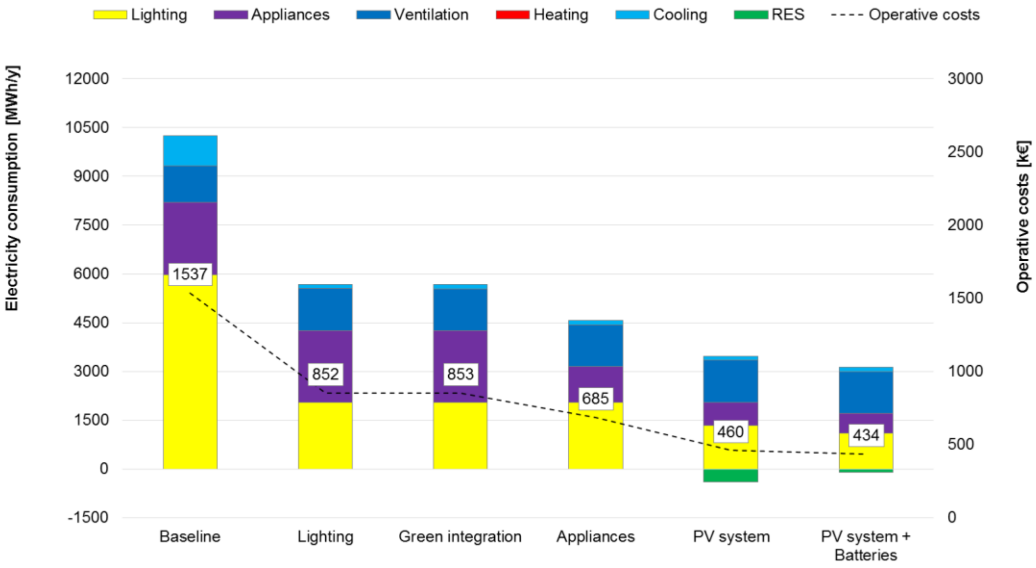

Figure 11-11. Yearly electricity consumption and operative costs in Waasland for solution set 2.

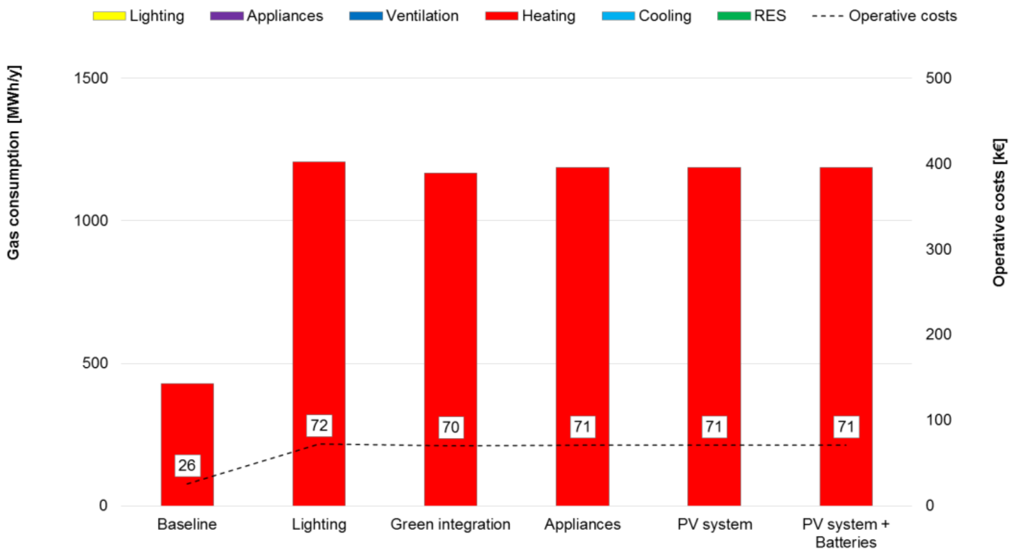

Figure 11-12. Yearly gas consumption and operative costs in Waasland for solution set 2.

11.5 Economic analysis

Two different studies have been done for the 2 solution-sets proposed:

The installation of efficient lighting (LED) with better control strategy, addition of fiberglass insulation in walls, ground and roof, greenery on south-east wall, more energy efficient appliances, a new heat recovery system and PV panels for electricity production would have a payback time of 5.77 years:

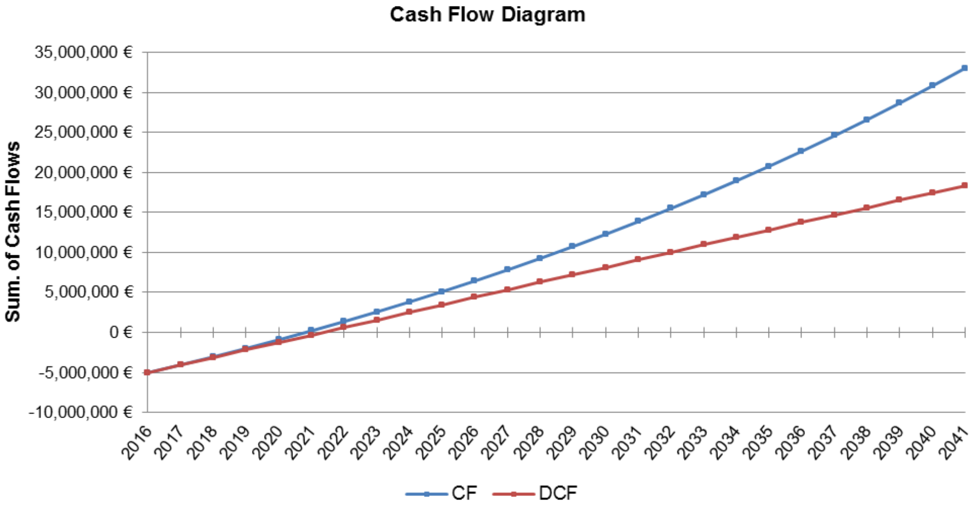

Figure 11-13 Cash flow diagram S1-3-4-5-6.1

A similar study was done in order to evaluate a variation of solution set 1, obtaining solution set 2. The heat recovery system would be replaced by the electrical storage in order to take more advantatge of the PV generation. In this case, the primary energy savings were the same and the economic analysis showed a similar number, 5.89 years.

11.6 Final considerations

The solution set here described is balanced on the specific needs of the Waasland building and the climate conditions of Sint-Nikklas.

Waasland shopping centre is a big shopping centre (45,000 m² of retail space) with only one floor. Therefore, there is an important area available for installation of renewable energy sources (such as PV panels). However, parking is located on the roof. Therefore, the most suitable solution would be to install PV on parking canopies which will also work as shading system. All the individual measures proposed have high replication potential in shopping centres in both heating and cooling dominated climates. However, depending on the combination of the different solutions forming a solution-set, different options could be proposed, for different type of shopping centres (for instance, the improvement of insulation and heat recovery would be suitable for heating dominated buildings, whilst efficient lighting and vegetable wall would be applied for reducing the cooling needs mainly). Therefore, after the study, two solution-sets were proposed for Waasland shopping center.

A summary of the solution-sets studied and the economic assessment performed is shown in Table 11-4**Error! Reference source not found.**.

Table 11-4. Summary of the solution sets studied for the Waasland reference building.

Solution-set	Individual solutions	Investment	Operation costs savings 1st year	Payback	%PE savings	%TCO_{eq} savings
Solution-set1	- Lighting - Green integration - Appliances - Heat Recovery - PV system	4,281,719.00 €	865,070.01 €	5.77 years	58.9%	59.2%
Solution-set2	- Lighting - Green integration - Appliances - PV system - Electrical storage	4,809,819.00 €	789,448.44 €	5.89 years	58.9%	55.7%

12 Grand Bazar (Antwerp - Belgium)

Grand Bazar (Figure 12-1 and Figure 12-2) is a shopping centre located in a spacious historic building (1885) on a historic spot in the heart of Antwerpen, close to the Groenplaats and the Eiermarket.

The entire building accommodates hotels, restaurants, etc., that do not belong to the Grand Bazar. Hence the different heights depending the orientation.

The shopping centre consists of four floors. One below and three above ground level. All of them destined to shops, food and medium stores, restaurants and cafeterias and warehouses. On the ground floor a corridor crosses the whole length of the building giving access to every establishment. The central part is an open space that communicates the three floors above ground, closed by a skylight on the ceiling that provides natural lighting to the common spaces.

Figure 12-1: Grand Bazar (Antwerp) building view.

Figure 12-2: Grand Bazar (Antwerp), building view.

The building is located in the city centre of Antwerpen, Belgium (Figure 12-3), at 7m above the sea level.

Figure 12-3. Satellite view of Grand Bazar shopping centre. Source: Google map.

The shorter building axis is facing absolute north. Therefore, the main building facades are oriented towards east and west.

12.1 Technological active-installation check-up

In the building, we have assumed non-condensing boilers for heating and heat pump for cooling purposes. There is not a heat recovery system.

We considered the following efficiencies to estimate the electricity consumption:

- Gas boiler efficiency: 0.8
- Air-to-water heat pump EER: 2.5

The heating demand of the mall has been calculated by imposing a set point temperature of 20°C from 7 am to 9 pm and a setback temperature of 15°C during night. The cooling demand has been calculated by imposing a set point temperature of 23°C from 7 am to 9 pm. The cooling system is turned off during the night. No additional air humidification is considered during the winter time.

The heating and cooling system are shut off on Sunday and closing days.

12.2 Analysis of energy consumption. Baseline simulation.

The graphs in Figure 12-4 and Figure 12-5 show the heating and cooling demand ratios per each thermal zone and the distribution of final energy (electricity/gas) per use (for the whole building), respectively. It can be seen that the highest electricity consumption is due to the lighting.

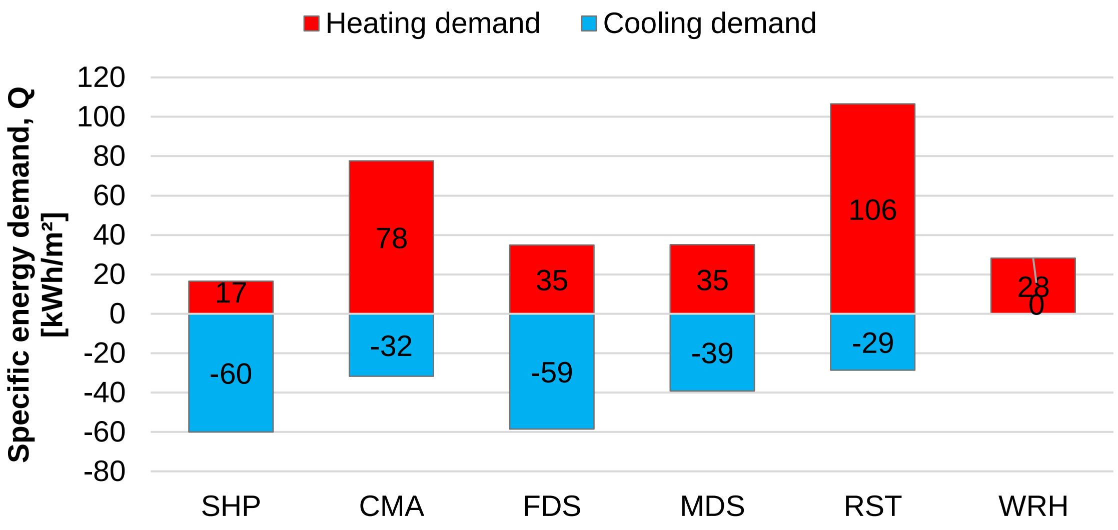

Figure 12-4. Heating and cooling demand ratios of each type of zone: shops (SHP), common areas (CMA), food store (FDS), midsize store (MDS), restaurant (RST), warehouse (WRH).

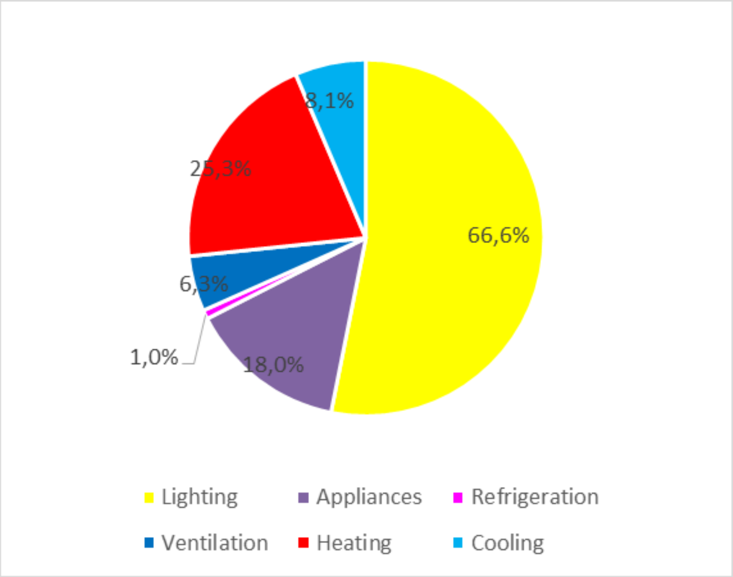

Figure 12-5. Distribution of final energy uses of the whole building.

12.3 Selection of suitable solutions

Grand Bazar is a shopping centre located in a spacious historic building. In this case, since the building has been evaluated as heating and cooling dominated, the solution set proposed is focused on the reduction of both consumptions. Taking into account the possibility of installing PV panels on the roof, the primary energy reduction could be reduced more; however, since this option is not completely confirmed (because the shopping centre shares the overall building with other uses), a solution-set without PV installation could be also applied.

Table 12-1 reports a description of the solution set proposed for the Waasland reference building.

Table 12-1. Description of the solution set studied for the Grand Bazar reference building.

Solutions		Description	Expected energy savings	Expected impact on comfort
1	**Efficient lighting and control**	Lighting power density is reduced down to 10 W/m² in the common areas and galleries and 18 W/m² in the vending area (shops, midsize stores, food store) because of the installation of LED lamps. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.	50% reduction of electricity consumption due to lighting 50% cooling need reduction	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall.
2	**Appliances replacement**	The appliances will be exchanged in maintenance cycles with high efficiency products. It is assumed a reduction of 50% of the energy consumption ratios used as baseline.	38% electricity consumption in the areas 15% cooling consumption reduction	The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.
3	**Cooling set point management**	The actual cooling setpoint is 23 °C, it would be possible to increase this value by 25ºC. On the other side, a better control could be used by modulating the cooling setpoint according to the outside temperature in order to prevent big temperature difference between inside and outside that can lead to thermal discomfort to costumers in both summer and mid-season.	35% Cooling demand reduction	A better control of indoor temperature during summer and mid-season preventing thermal shock because of high temperature difference between indoor and outdoor.
4	**Heat recovery system**	The heat exchanger will have a performance of 50% and will recover the residual heat that is released to the exterior in the ventilation process.	32% reduction of heating consumption	Softening of comfort conditions.
5.1	**Photovoltaic plant**	The only PV plant can improve the “green-energy” produced on-site and decrease the energy imported from the grid. If the PV is combined with a battery energy storage system, advantageous situation are for suppling a dedicated load (e.g. lighting system) or shave the peak (only to smooth the energy profile and not strictly related to the en. prices during the day).	Part of the el. consumption can be covered combined with a self electricity production with enclosed CO_2 emissions reduction, depending on the number of PV panels installed.	-

12.4 Energy savings

The graph in Figure 12-6 shows the actual yearly final energy consumption (in terms of electricity and gas consumptions) of the baseline model for the overall shopping mall and the potential energy savings of the energy efficiency measures described.

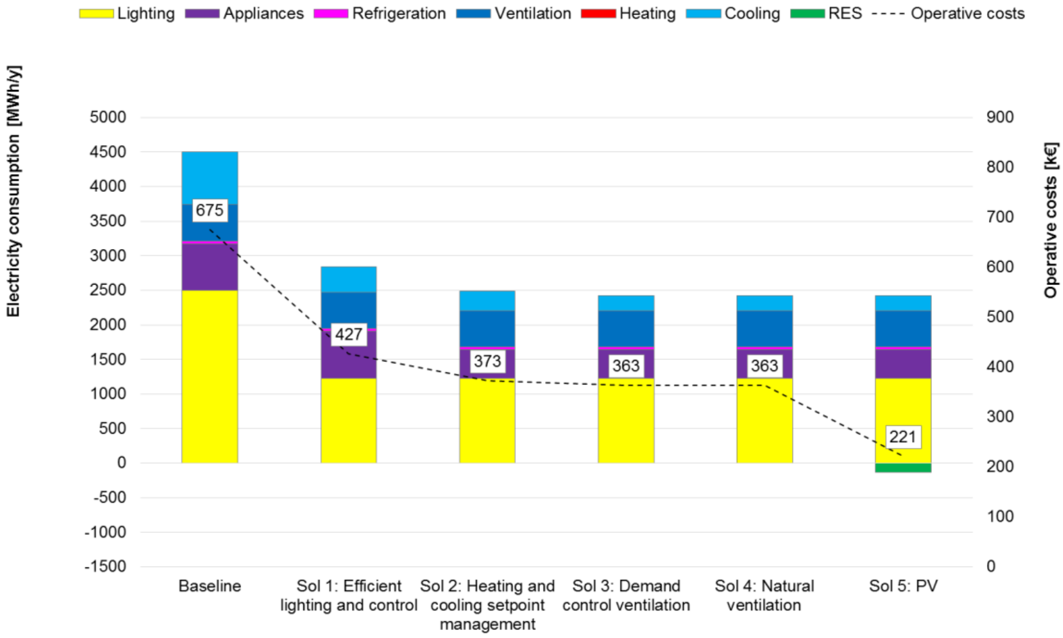

Figure 12-6 Yearly final energy consumption (electricity) in Grand Bazar shopping centre.

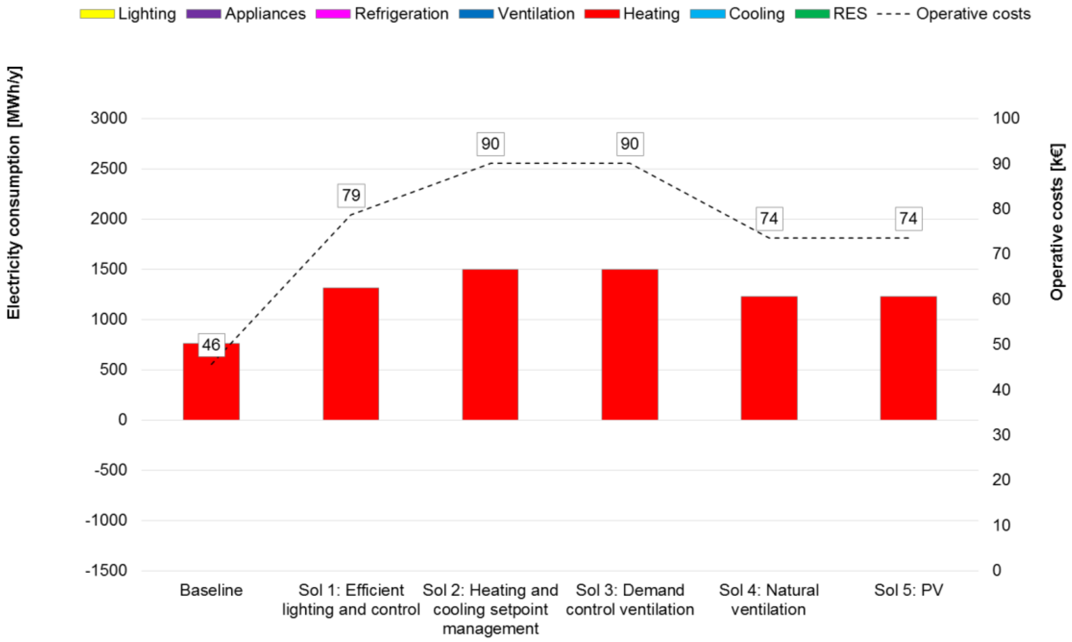

Figure 12-7 Yearly final energy consumption (gas) in Grand Bazar shopping centre.

The graph in Figure 12-8 shows the actual yearly primary energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described.

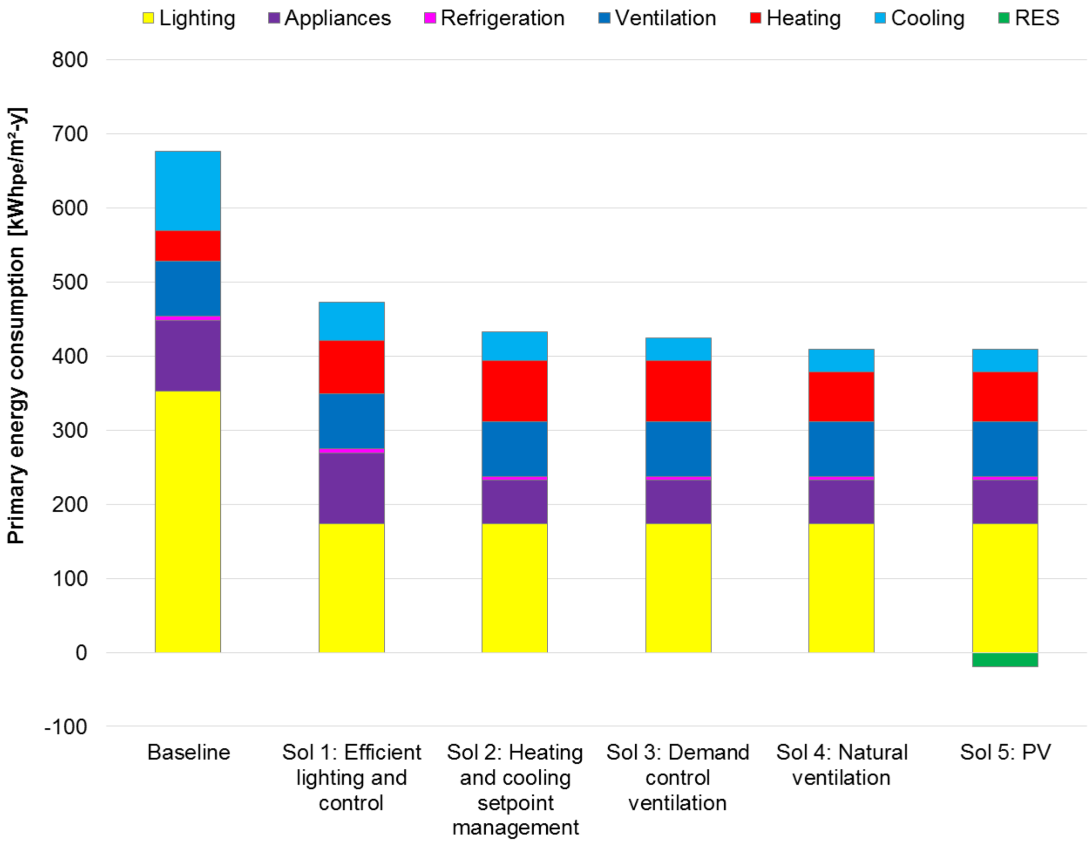

Figure 12-8. Yearly primary energy consumption in Grand bazar shopping centre

12.5 Economic analysis

The installation of efficient lighting (LED) with better control strategy, more energy efficient appliances, a new heat recovery system and PV panels for electricity production and the reduction of two degrees the setpoint temperature for cooling would have a payback period of 5.07 years with an investment of around 1 M€.

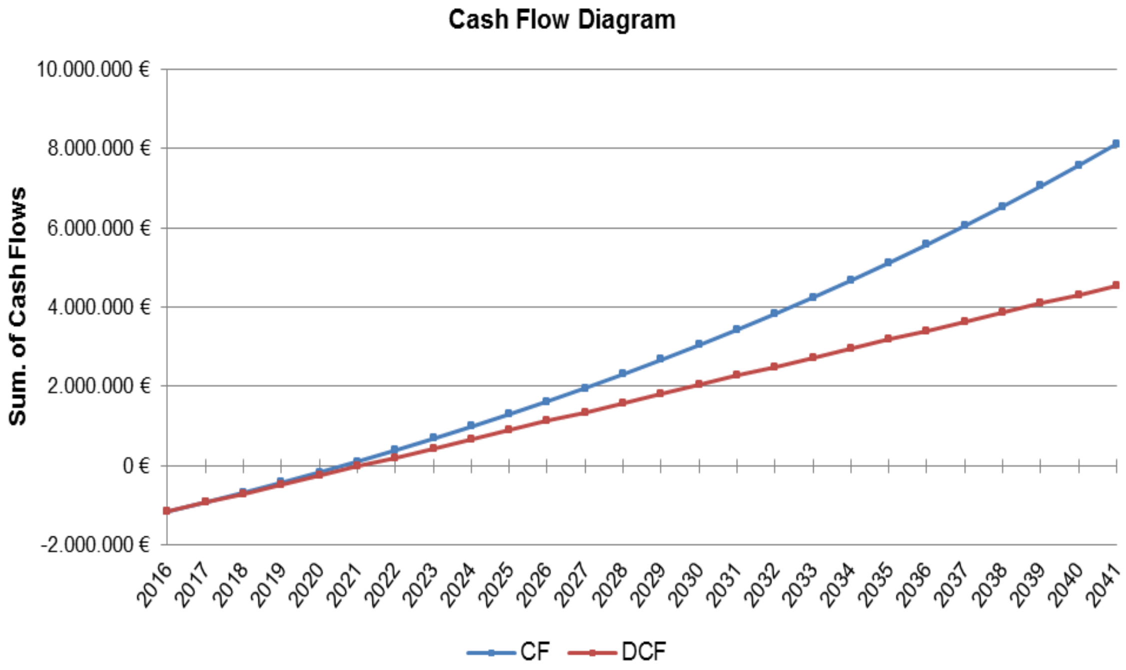

Figure 12-9 Cash flow diagram S1-2-3-4-5.1

A summary of the solution-sets studied and the economic assessment performed is shown in Table 12-2.

Table 12-2. Solution set studied for Grand Bazar reference building.

Solutions-Set	Individual Solutions	Total investment	Operation costs savings 1st year	Payback Period	%PE savings	%TCOeq savings
Solution-Set 1	• Lighting • Appliances • Tset Cooling • Heat recovery • RES – PV	993.520,00 €	224.569,30 €	5,07 years	40%	50%

12.6 Final considerations

The solution set here described is balanced on the specific needs of the Grand Bazar building and the climate conditions of Sint-Nikklas.

Grand Bazar is a shopping centre located in a spacious historic building. In this case, since the building has been evaluated as heating and cooling dominated, the solution set proposed is focused on the reduction of both consumptions. Taking into account the possibility of installing PV panels on the roof, the primary energy reduction would be 40% with around 5 years payback time; however, since this option is not completely confirmed (because the shopping centre shares the overall building with other uses), a new solution-set could be defined with the following efficient measures:

1	Efficient lighting and control
2	Appliances replacement
3	Cooling set point management
4	Heat recovery system

This solution-set could be applied in those shopping centres without available area for installing solar panels. In this particular building, the reduction of primary energy would be 36% and 4.86 years of payback time. The solution-set proposed would be a high replication for those buildings without external surfaces.

Conclusions

A solution-set is defined as a combination of passive and efficient active measures, utility equipment and energy generation technologies. The measures are integrated in the set looking for and exploiting synergies among HVAC, lighting, refrigeration, energy use as well as for building correlated services (parking, RES harvesting and local energy production etc.). The solution-sets shall accomplish three specific targets, which are:

- 75% energy consumption reduction (compared to the baseline);
- 7 years PBT;
- keep an acceptable IEQ level.

Eleven buildings have been studied with a close interaction with the owners/energy managers. Per each reference building, a list of activities have been performed, namely:

- Technological active-installation check-up
- Analysis of energy consumption. Baseline simulation
- Selection of suitable solutions
- Energy savings evaluation
- Economic analysis
- Final consideration

Within the CommONEnergy project (mainly in work packages 3 and 4), different energy efficiency measures have been studied and they represent important element of the identified solution-sets. The description of the different identified energy efficiency measures and the expected impacts considering both energy savings and comfort are summarized in Table 12-3.

Table 12-3. Energy conservation and energy efficiency measures studied.

Energy efficiency measures (individual solutions)		Description	Expected impact in HVAC consumption	Expected impact in comfort
1	**Geothermal heat pump**	Installation of a new GHP replacing an old one in the building.	Increase in the performance of the new heat pumps.	Improvement in the comfort conditions due to the new distribution systems.
2	**Efficient lighting**	Installation of more efficient lighting system (LED) and advanced control management.	Reduction in electricity and cooling consumption. Increase of heating demand.	Visual comfort and perception is more stable and natural. The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.
3	**RES integration – PV panels**	On site RES installation to produce electricity increasing the self-consumption and self-production and thus reduce the amount extracted from the grid when available area. If the PV is combined with a battery energy storage system, advantageous situation are for suppling a dedicated load (e.g. lighting system) or shave the peak (only to smooth the energy profile and not strictly related to the energy prices during the day).	Generation of electricity production.	If PV panels are installed in canopies, it will create shaded parking lots, which are preferred from customers especially during the summer period.
4	**Efficient appliances**	Exploiting existing systems and replacement of new more efficient appliances if possible.	Reduction in electricity and cooling consumption. Increase of heating demand.	The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.
5	**Natural ventilation**	Installation of natural ventilation through openable windows and advanced control strategies.	Reduction in cooling and ventilation needs.	Lower ceiling surface temperature improve thermal comfort in Summer. Increasing the air velocity within the indoor environment improves the

Energy efficiency measures (individual solutions)		Description	Expected impact in HVAC consumption	Expected impact in comfort
				comfort sensation of customers at high indoor temperatures. The use of ventilative cooling could have a great impact in indoor temperature especially during mid-season and summer.
6	**Heat recovery system**	Installation of heat recovery system and advanced control strategies.	Reduction in heating demand.	-
7	**Refrigeration**	Installation of new refrigeration units using CO2 as refrigeration fluid. Installation of closed cabinets.	Reduction in refrigeration and heating demand.	More uniform temperature distribution between cabinets corridors and the rest of the supermarket.
8	**Insulation**	Installation of new insulation in construction walls/floors/roofs	Reduction in heating and cooling demand.	Softening of comfort condition on both summer and winter period
9	**Reflective coating**	Application of reflective coatings (70-90% reflectivity) in external walls.	Small reduction in cooling demand	Indoor surface roof temperature will be lower or higher depending on the season resulting in a more uniform temperature inside the zone with effect on costumers thermal sensation
10	**Free cooling**	Mechanical free cooling	Reduction of cooling demand	Reduction of the peak temperature during day especially during mid-season; lower temperature during the first opening hours.
11	**Heat pumps water loop**	A water loop acts as source for a number of electric reversible heat pumps which provide climate control on the various thermal zones. Heat recovery is performed collecting heat from the condenser/gas cooler of the refrigeration system in the cold season and transferred to the heat pumps	Reduction of heat pumps and auxiliary heater electricity consumption in the cold season.	-

Energy efficiency measures (individual solutions)		Description	Expected impact in HVAC consumption	Expected impact in comfort
		water loop in order to maintain a certain temperature.		
12	**Heating & Cooling setpoint management**	To set more relaxed comfort temperature ranges.	Reduction in heating and cooling demand.	Impact on thermal comfort can be monitored by means of measurement and interviews campaigns.
13	**Demand control ventilation**	The amount of outdoor ventilation is adjusted depending on the inflow of people and/or the level of CO_2.	Reduction in ventilation consumption.	Even though the amount of outdoor ventilation might be lower than baseline solution, no impact of indoor air quality is expected because air changes are delivered just when they are needed.
14	**Revolving doors**	Installation of revolving doors in the main entrances.	Reduction in heating demand and infiltration losses.	The impact on thermal comfort is expected especially in the zone adjacent to entrance where the possibilities of cold draughts, especially during winter season are consistently limited.
15	**Shadings**	Installation of shadings in south façade glazing	Reduction of cooling demand	Improve the comfort during the occupied hours. Softening discomfort due to overheating especially in summer and mid-season period
16	**Green integration**	Installation of exterior wall covered with climbing vegetation (foliage fixed with wiring).	Small energy savings during summer conditions by solar shading and thermal energy savings by reduced air infiltration rates because of the vegetation.	Improve of thermal comfort inside the building and “green” visual impact. Improvement of microclimate in the neighbourhood of shopping center building by humidity and dust PMs. Improved rainfall water management.

For the identification of suitable energy efficiency measure and, finally, of the solution-set, the communication with the owners/energy managers from the shopping centres chosen as reference buildings has been effective and very important for the validation of the obtained results. After a first proposal of solution-sets, an interview was performed to the main contacts from the shopping centres and their feedbacks were taken into account for the finalization of the activity. In general, the feedbacks were quite positive and they provided meaningful drivers to fix the configuration of retrofitting solution-sets. The full interviews can be found in Annex II.

A final step for the finalization of the task consisted on a workshop with the owners/managers in order to show them the achieved results, and collect their feedbacks. Again, we obtained practical ideas and inputs to tune performed work, also considering possible implementation issues, while the feedbacks from them on the presented results was positive. The minutes of the workshops are reported in Annex III.

Finally, the description of the different solution-sets identified in each reference building, the expected energy savings, payback and replication potential is reported in Table 12-4.

Table 12-4. Identified solution sets.

Solution-set		Reference building	Expected energy savings/payback	Replication Potential
1	**Geothermal heat pump** **Modular climate adaptive multifunctional façade** **Effective artificial lighting equipment + control strategies**	Mercado del Val (Valladolid – Spain)	70% PE / 6.8 years	However, although the solution set was studied for Mercado del Val which is an historic building, the replication potential is quite high, since the energy efficient measure implemented and the façade system could be applied to other shopping centres with large glazed facade.
2	**Efficient lighting system and controls** **Efficient appliances** **Natural ventilation** **Insulation**	CitySyd (Trondheim – Norway)	61-66% PE / <7 years	There is a high replication potential for this solution-set for shopping centres in heating dominated climates and with openable windows.
3	**Efficient lighting system and controls** **Efficient appliances** **Natural ventilation** **Insulation** **Photovoltaic plant**	CitySyd (Trondheim – Norway)	75% PE/ 12-13 years	This solution-set should be analyzed more in deep in order to study if the economic analysis satisfies the requirements of the investment for the owner. On the other side, since a PV system is taken into account, the location of the shopping centre should show good perspectives for this installation (enough renewable resource and/or good economic conditions from grants or subsidies).
4	**Efficient lighting system and controls** **Replacement of refrigeration cabinets** **Building envelope thermal improvement** **Reflective coating** **Improving HVAC efficiency** **Coupling HVAC and refrigeration**	Coop Canaletto (Modena – Italy)	55% PE / 7.3-11 years	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). This solution set can potentially be replicated in small size supermarkets where energy consumption is mainly due to refrigeration.
5	**Efficient lighting system and controls** **Refrigeration – CO2** **Heat pumps water loop** **Natural ventilation**	Coop Valbisagno (Genoa – Italy)	40% PE / 7.2 – 11.1 years	This solution set proposed a heat pump water loop and it is sutiable to major shopping centres renovations which need HVAC system replacement. The measure selected for the refrigeration systems could be also generalized for systems based on a cascade system with CO_2 as refrigerant for the

Solution-set		Reference building	Expected energy savings/payback	Replication Potential
	PV plant			direct expansion LT (Low Temperature) equipment, and R134a as refrigerant for the MT (Medium Temperature) portion of the system; however the advantage of this technology is mainly in terms of environment aspects rather than energy savings.
6	**Efficient lighting system and controls** **Appliances replacement** **PV system**	Brent Cross (-UK)	55% PE / 7 years or 75% PE / 19.4 years	The replicability of this solution-set would be high for those location where the installation of a PV system is cost-effective, because of the ambient conditions are favourable or even the installation of a renewable system could receive any kind of subsidies from the government.
7	**Efficient lighting system and controls** **Heating and cooling setpoint management** **Demand control ventilation (DCV)** **Natural ventilation** **PV plant on gallery roof and parking canopies**	Katané shopping centre (Katania – Italy)	58% PE / 5.1–6.8 years	This solution-set has high retrofitting potential since it is mainly focused on the management of existing installations. Apart from the PV system, the energy efficient measures applied requires a low investment, therefore, from an economic point of view is really convenient when the shopping centre management has low budget for retrofitting purposes.
8	**Efficient lighting system and controls** **Efficient appliances** **Cooling set point control** **Natural Ventilation** **Photovoltaic plant** **Revolving doors**	Donauzentrum (Vienna – Austria)	26% PE / 3.2-3.8 years	Although it has a high replication potential, this solution-set does not offer very much improvements in energy consumption for buildings with existing good practices in energy sustainability, although it is possible to reduce by 25% the primary energy consumption thanks to an investment with a very short payback-time.
9	**Effective artificial lighting equipment + control strategies** **Building envelope thermal improvement** **Heat recovery and heating set point management**	Pamarys (Lithuania)	63% PE / 6.3 years	The measures proposed are easily replicable in other shopping centres in heating dominated climates. The replication potential is, therefore, limited to the reduction of heating needs (apart from the PV system). This solution-set would only be interesting for location with favourable conditions for the PV installation.

Solution-set		Reference building	Expected energy savings/payback	Replication Potential
	RES integration (PV panels + Wind turbine)			
10	**Effective artificial lighting equipment + control strategies**	Studlendas (Lituania)	50% PE / 5.7 years	The measures proposed are easily replicable in other shopping centres in heating dominated climates. The replication potential is, therefore, limited to improvements in heating needs (apart from the shadings in south façade, which is an energy measure for reducing cooling needs).
11	**Building envelope thermal improvement** **Heat recovery and heating set point management** **Façade shadings for solar control**	Waasland (Sint-Nikklas – Belgium)	60% PE / 6 years	All the individual measures have high replication potential in shopping centres for both heating and cooling needs.
12	**RES integration (PV panels + Wind turbine)**	Waasland (Sint-Nikklas – Belgium)	60% PE / 6 years	This solution-set is focused mainly on cooling dominated shopping centres. The integration of batteries means an increase of the investment which in many scenarios makes the installation not viable from an economic point of view. Nowadays, price of batteries is decreasing, nevertheless it is necessary to study any particular scenarios because depending on the country regulation, their installation could be economically feasible or not.
13	**Efficient lighting and control** **Appliances replacement** **Cooling set point management** **Heat recovery system** **Photovoltaic plant**	Grand Bazar (Antwerp – Belgium)	40% PE / 5 years	All the individual measures have high replication potential in shopping centres in heating and cooling dominated climates.
14	**Efficient lighting and control** **Appliances replacement** **Cooling set point management** **Heat recovery system**	Grand Bazar (Antwerp – Belgium)	36% PE / 4.9 years	The solution-set proposed would be replicable for those buildings without external surfaces for RES integration.

Analysing all the solution-sets, it can be noticed not all of them reach the 75% of primary energy reduction. Within the task group (extended to reference buildings representative people) the initial investment as well as the return of investment, are considered more important than high energy saving. Definitely, the economic impact of the retrofit and possible the improvement of customers' experience related to indoor environmental quality seems to be "more important" for the owners, energy managers, and retail developers in general. In general, the solution-sets chosen fulfil the 7 years payback, with a meaningful reduction of primary energy consumption and increasing rate of renewable sources.

Also considering the feedbacks we collected during the stakeholders' workshops, the identified solution-sets have a high replication potential, and the structured methodological framework enables to adjust them to different contexts, presenting, through standardised key performance indicators, energy, indoor environmental quality and economic achievable results. In this way investors, facility managers and designers can start a process for planning a shopping centre retrofitting with consistent figures of possible technology solutions and overall possible performance targets. Then, the first retrofitting concept must be detailed with dedicated modelling and simulation activity, by using tools as the ones developed within CommONEnergy project.

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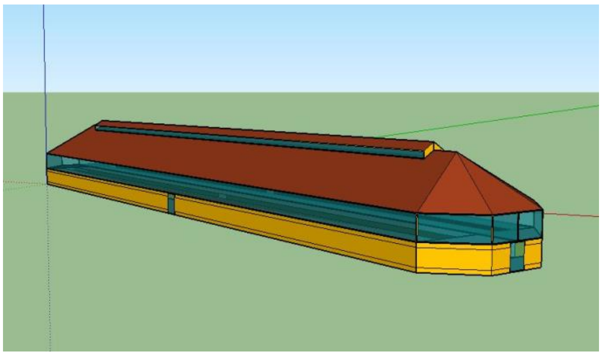
Annex I - Solution sets

Mercado del Val (Valladolid - Spain)

Building model (old building): input data summary

General data	
Gross floor area [m²]	2,280
Number of opening hours per day [h/d]	10
Number of opening days per week [d/w]	6

Thermal zone model



Number of thermal zones	9
First floor height [m]	3
Second floor height [m]	2.9
Zone typology	Zone group area [m²]
Shops	2,220
Common areas	-

Building envelope

Opaque envelope components	U-value [W/m²K]
External wall (A/B/C)	1.642/0.738/1.897
Roof (Interior/Exterior)	2.191/1.066
Floor (without radiant floor/with radiant floor)	1.243/0.507

Glazed envelope components	Ug [W/m²K]	g-value [-]
Windows	5.8	0.8
Doors	3.25	0.76

	Common areas		Shops	
	Value	Schedule	Value	Schedule
People density [pers/m²]	0.2	6:00-17:00	0.2	6:00-17:00
Lighting density [W/m²]	23.7	6:00-17:00	36.2	6:00-17:00
Electric equipment [W/m²]	0	6:00-17:00	10	6:00-17:00
Heating setpoint temperature [°C]	20	6:00-17:00	20	6:00-17:00
Cooling setpoint temperature [°C]	25	6:00-17:00	25	6:00-17:00
Ventilation rates [kg/hr·m²]	7.35	6:00-17:00	7.35	6:00-17:00
Infiltration rates [ach]	4	0:00–24:00	4	0:00-24:00

HVAC systems control and efficiency

Detailed information about energy systems of the building in Deliverable 6.3 section 2.1.4.

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time.

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.

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

It is necessary to calculate the energy demand for heating and cooling of the market, always assuming that a minimum comfort condition is reached (really not reached in the old building). To do this all the building characteristics and parameters described in Deliverable 6.3 document were taken in to account.

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 poor envelope conditions.

Simulation settings

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

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) (Meteotest, 2015).

Actual building energy consumption

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. Because the building was not operative since 2013, it was not possible to perform direct measurements.

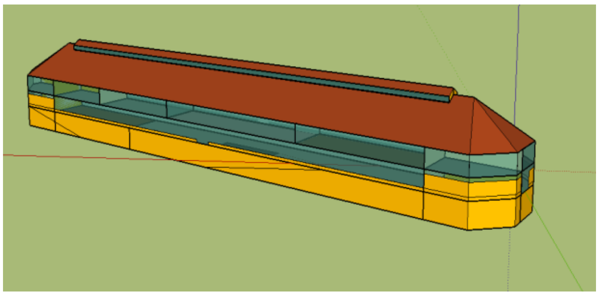
Due to this, to estimate the building energy demand dynamic simulation software was used (TRNSYS).

For more detailed information see Deliverable 6.3 (Antolín J., 2016) about the energy audit of the old building.

Building model (new building): input data summary

General data	
Gross floor area [m²]	4,800
Number of opening hours per day [h/d]	12
Number of opening days per week [d/w]	6

Thermal zone model



Number of thermal zones	22
Basement height [m]	3.7
Ground floor height [m]	3
First floor height [m]	2.9
Zone typology	Zone group area [m²]
Shops	3030
Technical rooms	555
Common areas	479
Restaurant	119
Parking	466
Services	286

Building envelope

Opaque envelope components	U-value [W/m²K]
External wall (1/2)	0.641/1.350
Roof	0.377
Floor	0.358

Glazed envelope components	Ug [W/m²K]	g-value [-]
North Windows	1.29	0.631
South Windows	1.29	0.333
East and West Windows	1.29	0.333

	Common areas		Shops		Restaurant		Technical rooms		Parking		Services	
	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule
People density [pers/m²]	0.14	6:00-17:00	0.14	6:00-17:00	0.14	6:00-17:00	0	-	0	-	0	-
Lighting density [W/m²]	10	6:00-17:00	15	6:00-17:00	10	6:00-17:00	0	-	10	6:00-17:00	0	-
Electric equipment [W/m²]	0	-	5	0:00-24:00	5	0:00-24:00	5	6:00-18:00	5	6:00-18:00	5	6:00-18:00
Heating setpoint temperature [°C]	20	6:00-16:00	20	6:00-16:00	21	6:00-16:00	20	6:00-16:00	20	6:00-16:00	20	6:00-16:00
Cooling setpoint temperature [°C]	24	6:00-16:00	24	6:00-16:00	25.5	6:00-16:00	24	6:00-16:00	24	6:00-16:00	24	6:00-16:00
Ventilation rates [kg/hr·m²]	7.35		7.35		7.35		7.35		7.35		7.35	
Infiltration rates [ach]	0.4	0:00-24:00	0.4	0:00-24:00	0.4	0:00-24:00	0.4	0:00-24:00	0.4	0:00-24:00	0.4	0:00-24:00

HVAC systems control and efficiency

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time.

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 have the possibility of free-cooling mode and a heat recovery performance of more than 65%.

Regarding the fridge 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 amount of 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.

Simulation settings

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

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).

Actual building energy consumption

At this stage is not possible the calibration as no real data is available at this moment, the building is still not operative. Once the building will be operative again and the monitoring system working, the calibration will be possible.

Solution set description

The solution set here described is balanced on the specific needs of Mercado del Val democase building and the climate conditions of Valladolid.

Solution 1: Geothermal heat pump

Objective

With this solution is possible to:

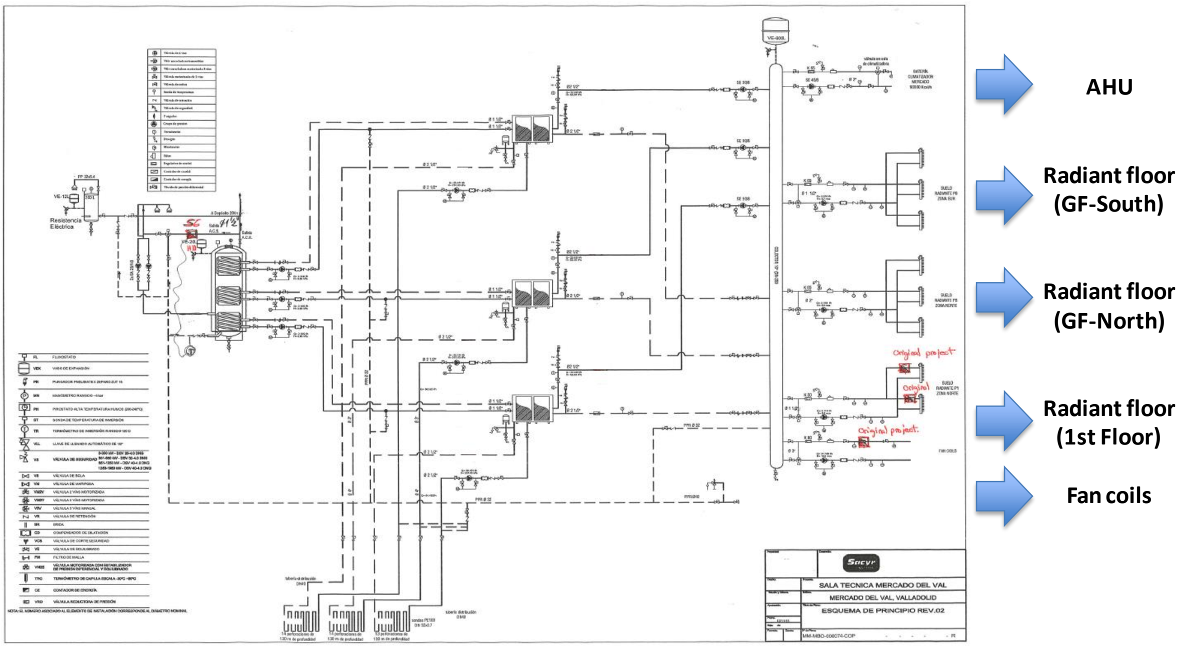
- Cover the heating and cooling demand of the building.
- Cover the DHW demand of the building.
- Reduce the amount of electricity.

Description

To supply both heating and cooling there are installed three reversible ground to water geothermal heat pumps, getting temperature from vertical boreholes done on the ground (42 boreholes of 120 m).

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.



Area of application

HVAC system.

Expected energy savings

There is an increase in the performance of the new heat pumps.

- Estimated COP and ERR of the old air to water heat pumps 3 and 2.5.
- Estimated COP and ERR of the new Geothermal heat pumps 3.22 and 5.02.

Expected impact on comfort

There is an improvement in the comfort conditions due to the new distribution systems.

Expected investment costs

Real costs of the demo-case:

- Geothermal heat pumps: 84,000 €
- Bareholes: 183,500 €
- Geothermal probes: 30,000 €
- Distribution system: 34,000 €
- Hydraulic system: 5,000 €

Total: 336,500 €

Solution 2: Multifunctional façade

Objective

With this solution is possible to:

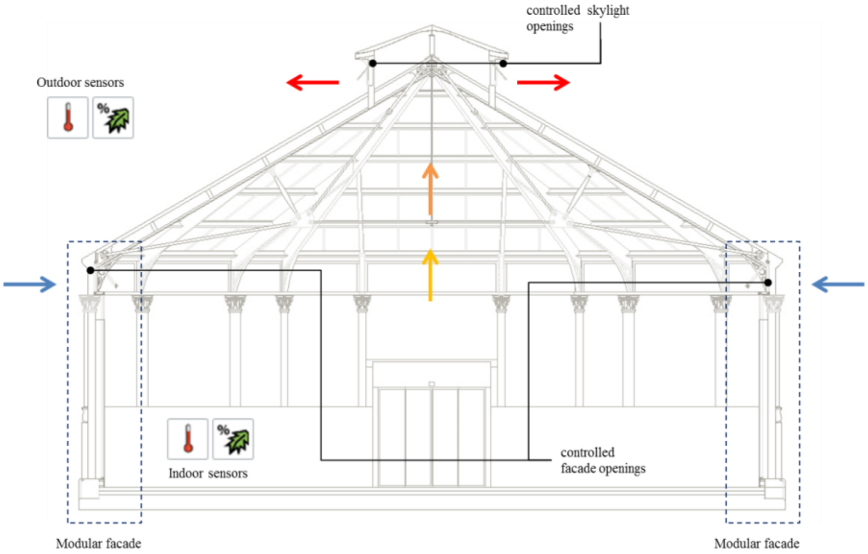
- Reduce the heating and cooling demand of the building.
- Reduce energy consumption for ventilation.
- Reduce the amount of direct solar radiation entering in the building.

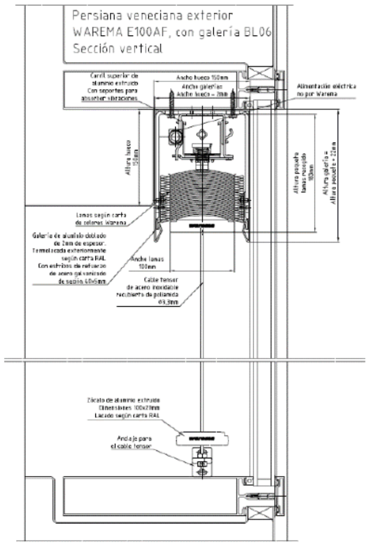
Description

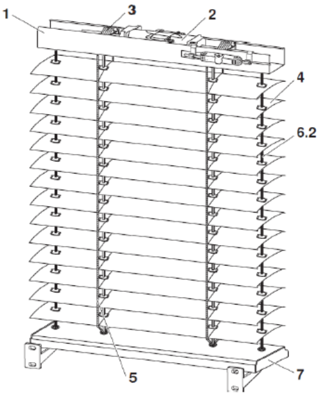
Multifunctional façade:

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

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).







Area of application

Façade and control system.

Expected energy savings

More than 75% of heating demand reduction. This reduction includes also the improvement coming from the new structure of the building.

More than 80% of cooling reduction. This reduction includes also the improvement coming from the new structure of the building.
Mechanical ventilation electricity consumption reduction.
Infiltration reduction.

Expected impact on comfort

Improve the comfort during the occupied hours.
Increasing the air velocity within the indoor environment improves the comfort sensation of customers at high indoor temperatures.

Expected investment costs

Real costs of the demo-case:

- Glazing: 182,686 €
- Windows for natural ventilation: 146,877 €
- Shadings: 55,968€
- iBEMS: 50,000 €

Solution 3: Effective artificial lighting equipment + control strategies

Objective

To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off
With this solution is possible to reduce the electricity consumption of the building. By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have a higher impact on building energy consumption (this solution would be very interesting in combination with Solution 1).

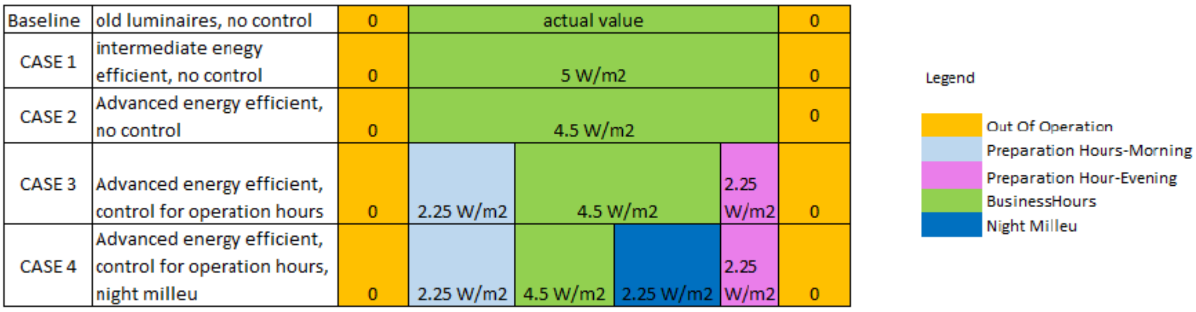
Description

Five different cases have been studied:

- CommONEnergy project.
- Case 1: Intermediate energy efficient lighting with no control.
- Case 2: Advanced energy efficient lighting with no control.
- Case 3: Advanced energy efficient lighting with control for operation hours.
- Case 4: Advanced energy efficient lighting with control for operation hours and night milieu.

Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.

For Common areas:

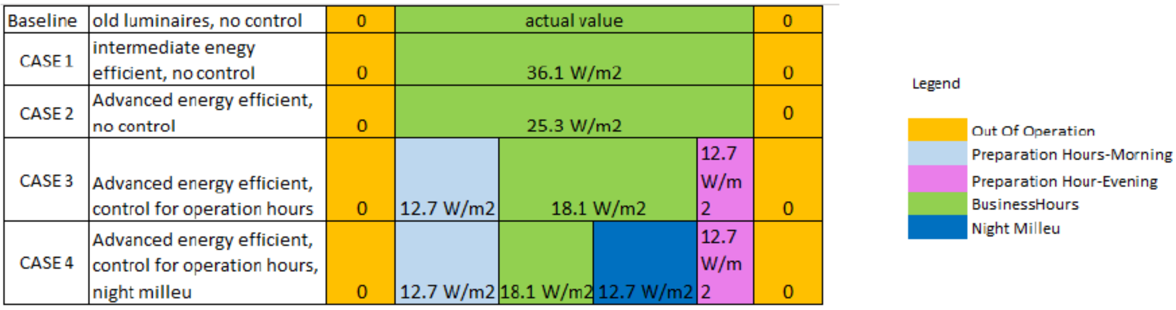


Baseline	old luminaires, no control	0	actual value				0
CASE 1	intermediate enegy efficient, no control	0	5 W/m2				0
CASE 2	Advanced energy efficient, no control	0	4.5 W/m2				0
CASE 3	Advanced energy efficient, control for operation hours	0	2.25 W/m2	4.5 W/m2		2.25 W/m2	0
CASE 4	Advanced energy efficient, control for operation hours, night milleu	0	2.25 W/m2	4.5 W/m2	2.25 W/m2	2.25 W/m2	0

Legend

🟨 Out Of Operation
🟦 Preparation Hours-Morning
🟪 Preparation Hour-Evening
🟩 BusinessHours
🟦 Night Milleu

For shops:

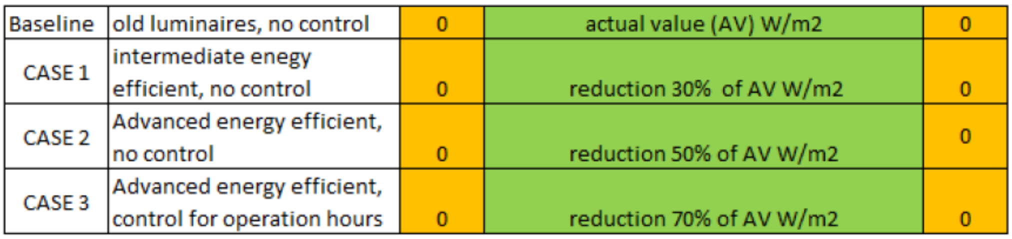


Baseline	old luminaires, no control	0	actual value				0
CASE 1	intermediate enegy efficient, no control	0	36.1 W/m2				0
CASE 2	Advanced energy efficient, no control	0	25.3 W/m2				0
CASE 3	Advanced energy efficient, control for operation hours	0	12.7 W/m2	18.1 W/m2		12.7 W/m2	0
CASE 4	Advanced energy efficient, control for operation hours, night milleu	0	12.7 W/m2	18.1 W/m2	12.7 W/m2	12.7 W/m2	0

Legend

🟨 Out Of Operation
🟦 Preparation Hours-Morning
🟪 Preparation Hour-Evening
🟩 BusinessHours
🟦 Night Milleu

For rest of areas:



Baseline	old luminaires, no control	0	actual value (AV) W/m2	0
CASE 1	intermediate enegy efficient, no control	0	reduction 30% of AV W/m2	0
CASE 2	Advanced energy efficient, no control	0	reduction 50% of AV W/m2	0
CASE 3	Advanced energy efficient, control for operation hours	0	reduction 70% of AV W/m2	0

Area of application

Artificial lighting of the shopping mall.

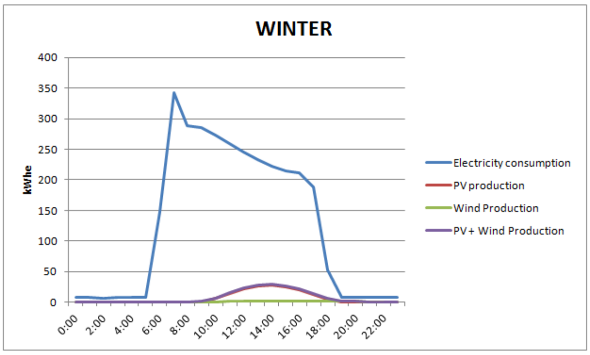
Expected energy savings	CommONEnergy project: 55% reduction in lighting consumption. Case 1: 66% reduction in lighting consumption. Case 2: 67% reduction in lighting consumption. Case 3: 73% reduction in lighting consumption. Case 4: 78% reduction in lighting consumption.
Expected impact on comfort	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping centre.
Expected investment costs	LED lighting: 4 €/m² (min.price, standard product). LED lighting: 14 €/m² (max. price, dimable, A++ product).

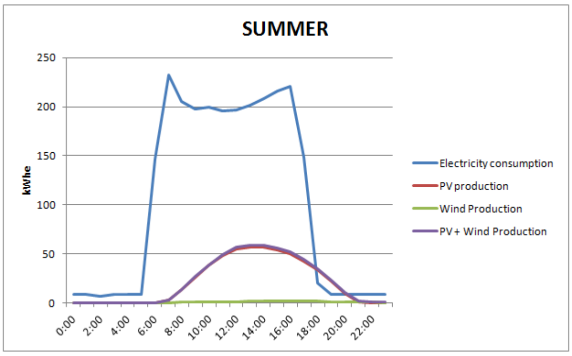
Solution 4: RES integration (PV panels + Wind turbine)

Objective On site RES are a good solutions to produce electricity increasing the self-consumption and self-production and thus reduce the amount extracted from the grid.

Description Good weather conditions but with restrictions coming from the location in the city centre and surrounded by a lot of other buildings and due to their historical character. Surface free of shadows to integrate PV tiles: 865 m² approximately.

- PV: due to their historical character, is not possible the integration of PV panels. But it would be interesting to study the integration of PV tiles or BIPV in the façade. Photovoltaic generation profile is suitable for the demand profile of the building because the photovoltaic generation peaks normally are going to coincide with the market demand peaks.
- Small wind turbine: almost discarded due to the aesthetical reasons and noises.





Load profiles will change due to other solutions.

Area of application Roof

Expected energy Production The yearly simulation performed give us the following energy production estimation:
Wind Power: 9,555 kWh/year
Photovoltaic: 123,533 kWh/year

Expected investment costs PV system (PV tiles): 150,000 €
Wind turbine (20 kW): 50,000 €

Results

The graph in Figure 10 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described in the previous section.

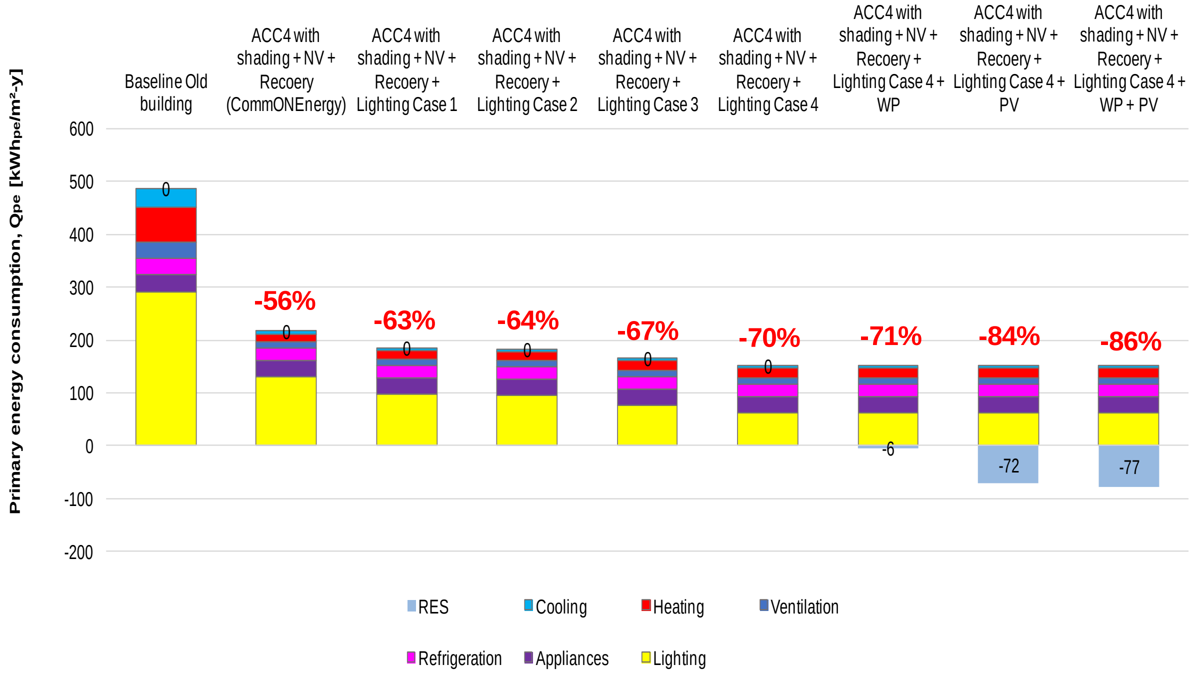


Figure 10. Yearly final energy consumption.

The economic analysis is based on the assumptions in Table 5.

Table 5. Economic analysis assumptions.

Assumptions	Value
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	5.04%
Energy costs	
Cost of electricity	0.1141 €/kWh
Electricity buy price annual variation	1.0%/year
Electricity sell price annual variation	1.0%/year
Installation ageing	0.5%/year
Operation costs	
Insurance	0.5% for PV 0.3% for WP
Taxes	28.0%
Maintenance	2.5% for PV 4% for WP
Contingency	5% from previous concepts

Annual variation	0.5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**.
The results of the cash inflows and outflows is shown over the 25 years period studied are shown in the graphs.
For this specific analysis the comparison has been made between the old building and the new building but only taking into account the fresh market itself, this means the ground floor in order to compare a similar surface and type of activity of the building and in this way to have coherent results.

Solutions		Description
1	**Geothermal Heat pump**	Installation of three reversible ground to water geothermal heat pumps.
2	**Multifunctional façade**	Improved glass wall envelope. Shading elements in the south façade (lamellas). Natural ventilation. iBEMS.

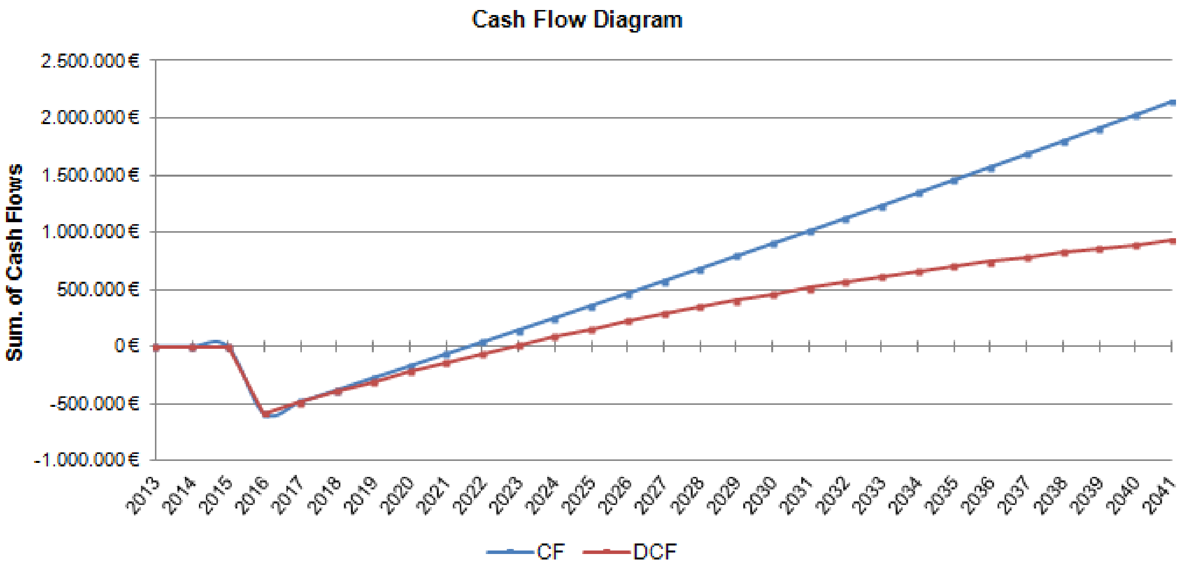


Figure 11. Cash flow diagram of solution 1-2.

The installation of the geothermal heat pumps together with the multifunctional façade would have a ROI period of 6.78 years.

Solutions		Description
1	**Geothermal Heat pump**	Installation of three reversible ground to water geothermal heat pumps.
2	**Multifunctional façade**	Improved glass wall envelope. Shading elements in the south façade (lamellas). Natural ventilation. iBEMS.
3a	**Lighting**	LED standard product

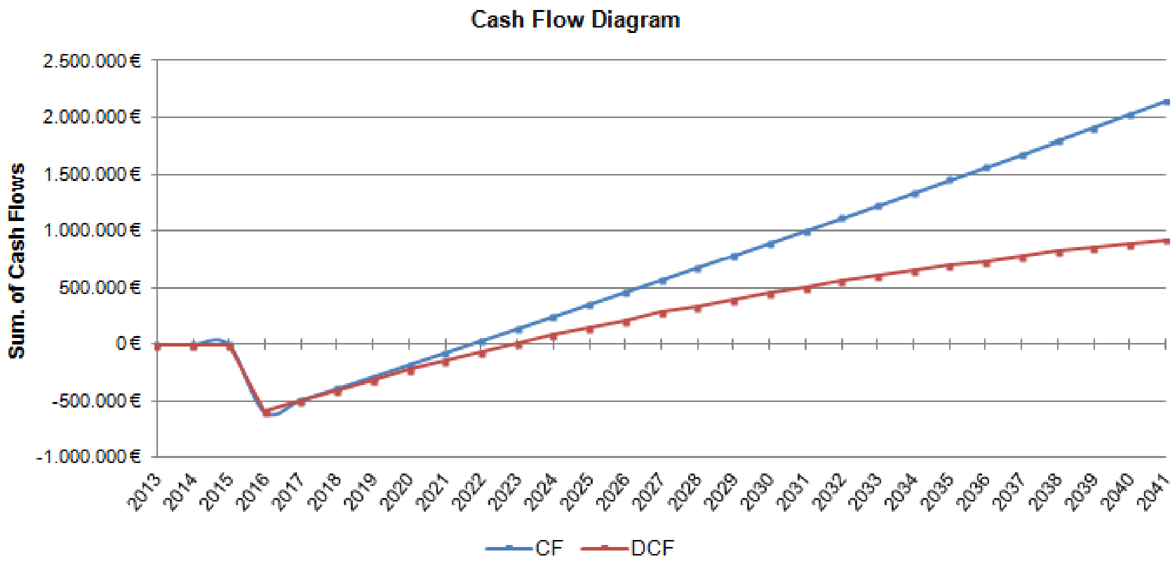


Figure 12. Cash flow diagram solutions 1-2-3a

The installation of the geothermal heat pumps and multifunctional façade together with the standard LED would have a ROI period of 6.86 years.

Solutions		Description
1	**Geothermal Heat pump**	Installation of three reversible ground to water geothermal heat pumps.
2	**Multifunctional façade**	Improved glass wall envelope. Shading elements in the south façade (lamellas). Natural ventilation. iBEMS.
3b	**Lighting**	LED dimmable, A++ product

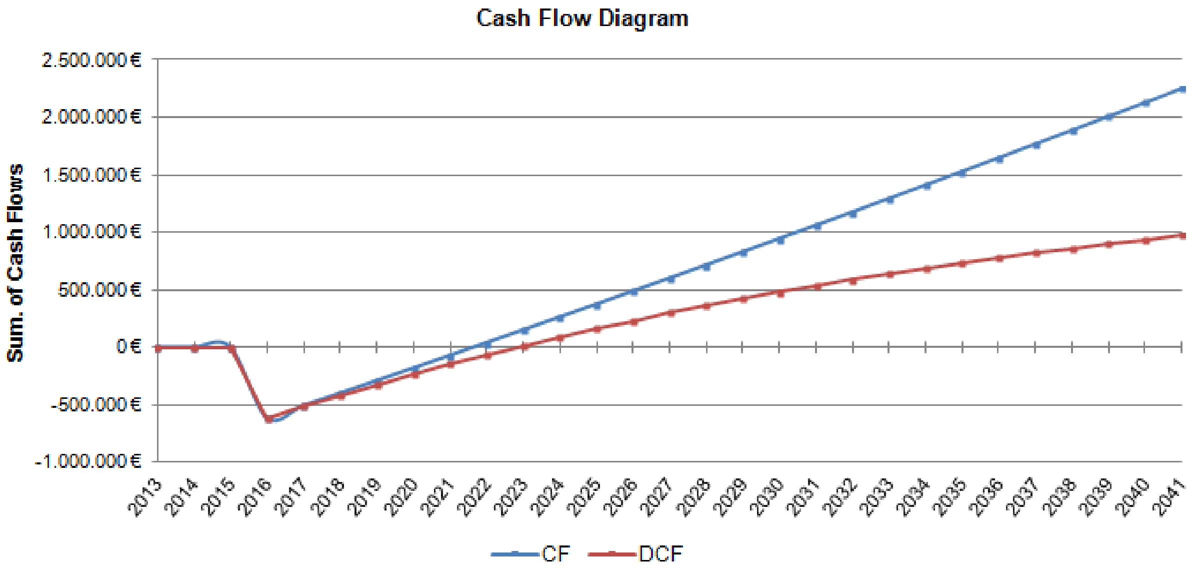


Figure 13. Cash flow diagram solutions 1-2-3b

The installation of the geothermal heat pumps and multifunctional façade together with efficient lighting (LED) with better control strategy would have a ROI period of 6.79 years.

Solutions		Description
1	**Geothermal Heat pump**	Installation of three reversible ground to water geothermal heat pumps.
2	**Multifunctional façade**	Improved glass wall envelope. Shading elements in the south façade (lamellas). Natural ventilation. iBEMS.
3b	**Lighting**	LED dimable, A++ product
4a	**RES**	PV

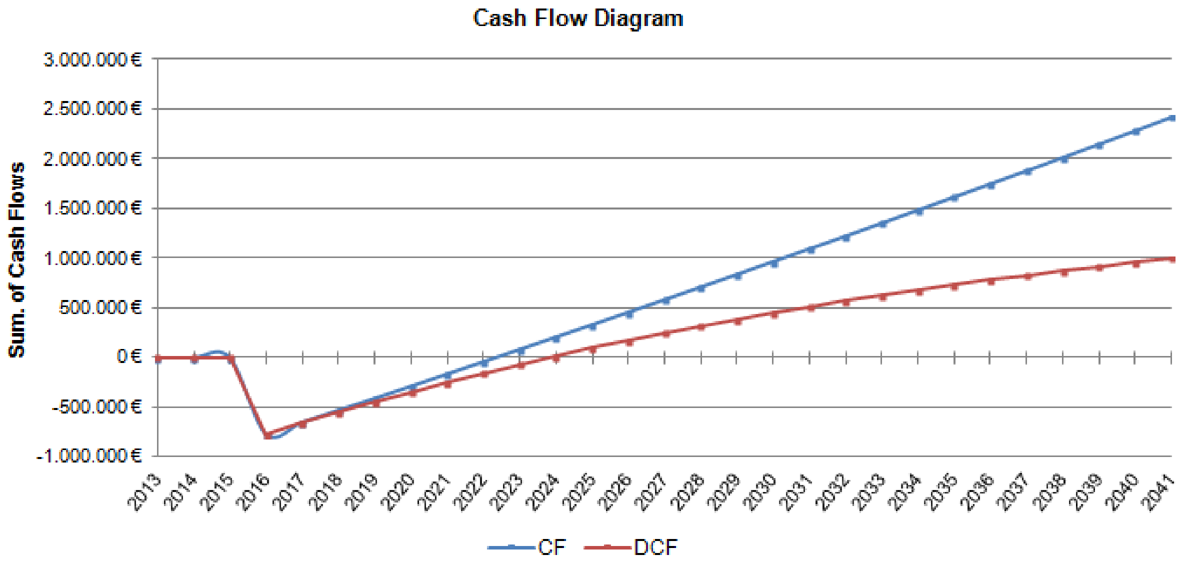


Figure 14. Cash flow diagram solutions 1-2-3b-4a

The installation of the geothermal heat pumps and multifunctional façade together with efficient lighting (LED) with better control strategy and the PV tiles would have a ROI period of 7.82 years. Out of scope (<7 years).

Solutions		Description
1	**Geothermal Heat pump**	Installation of three reversible ground to water geothermal heat pumps.
2	**Multifunctional façade**	Improved glass wall envelope. Shading elements in the south façade (lamellas). Natural ventilation. iBEMS.
3b	**Lighting**	LED dimable, A++ product
4b	**RES**	Wind Power

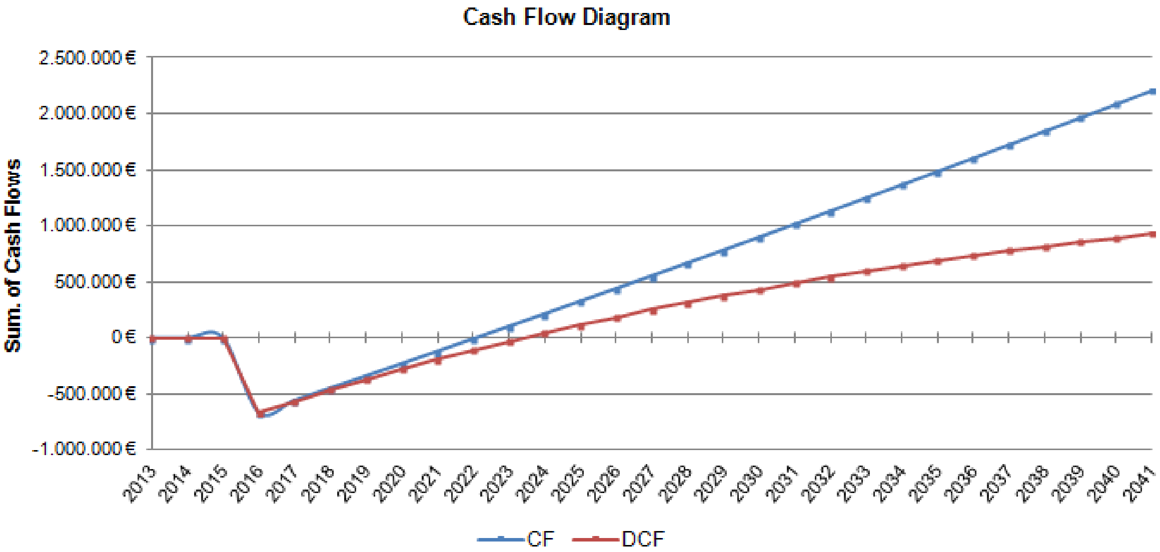


Figure 15. Cash flow diagram solutions 1-2-3b-4b

The installation of the geothermal heat pumps and multifunctional façade together with efficient lighting (LED) with better control strategy and the WP system would have a ROI period of 7.44 years. Out of scope (<7 years).

Solutions		Description
1	**Geothermal Heat pump**	Installation of three reversible ground to water geothermal heat pumps.
2	**Multifunctional façade**	Improved glass wall envelope. Shading elements in the south façade (lamellas). Natural ventilation. iBEMS.
3b	**Lighting**	LED dimable, A++ product
4a	**RES**	PV
4b	**RES**	Wind Power

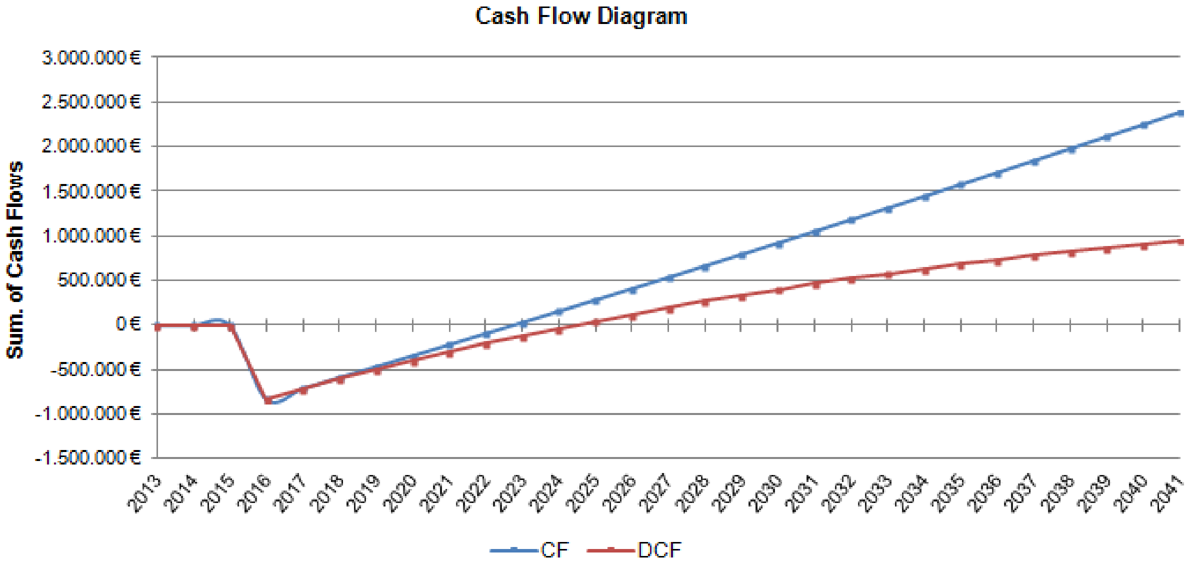


Figure 16. Cash flow diagram solutions 1-2-3b-4a-4b

The installation of the geothermal heat pumps and multifunctional façade together with efficient lighting (LED) with better control strategy and the RES system (PV tiles + WP) would have a ROI period of 8.42 years. Out of scope (<7 years).

City Syd (Trondheim - Norway)

Building description

City Syd shopping centre is a suburban mainly car-dependent shopping centre, built on the outskirts of Trondheim. The E6 motorway which is the main north to south route in Norway runs along the western side of the shopping centre. Opened in 1987 and covering an area of 28,500 m², it was redeveloped in 2000 and it is now 38,000 m² on three floors, with 1,000 outdoor parking spaces. It houses 70 retail units. City Syd was the largest shopping centre in the region until 2009, and it remains one of the largest in central Norway. An expansion of the shopping centre is proposed.
The part of the centre assessed in CommONEnergy is nearly 20 000 m² (see Figure 17).

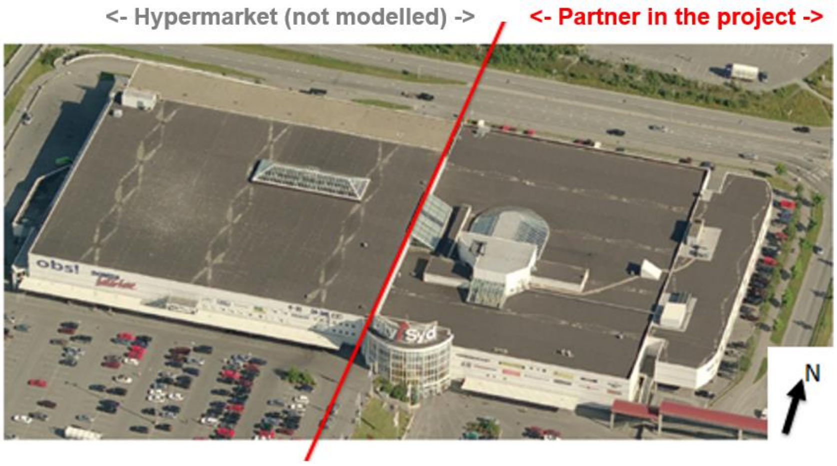


Figure 17. Aerial photo of the shopping centre. The part of the centre which is taking part in the study is approximately 20 000 m² floor area.

Actual state

The heating and cooling needs are covered by 2 air to water heat pumps (AWHP), supplemented by district heating and two additional cooling machines when needed. The dual AWHP are connected to the main ventilation units by heating/cooling coils, and switched from heating to cooling mode in the mid-season. Comfort is mainly obtained by heating and cooling of the ventilation supply air, as space heating only occurs in the entrance area. In addition to a handful of air curtains, adjacent to cargo doors, which are also connected to district heating.

District heating

District heating is used for the air curtains in the main entrance area, as well as a supplement to the AWHP for heating the ventilation supply air. Additional aero-tempers are installed in cargo entrances and there are snow melting systems in the entrance areas (some are configured to reduce the district heating return temperature). Finally, water is heated for tap water application with district heating (and raised locally by electricity in restaurants, cafes and other consumers requiring higher temperature levels). The district heating demand correlates with outside temperatures, number of visitors in winter (opening and closing of doors on a day to day basis) and possibly wind conditions as the customer entrance is located to the open parking lot towards the south (which correspond with the prevailing wind direction in winter).

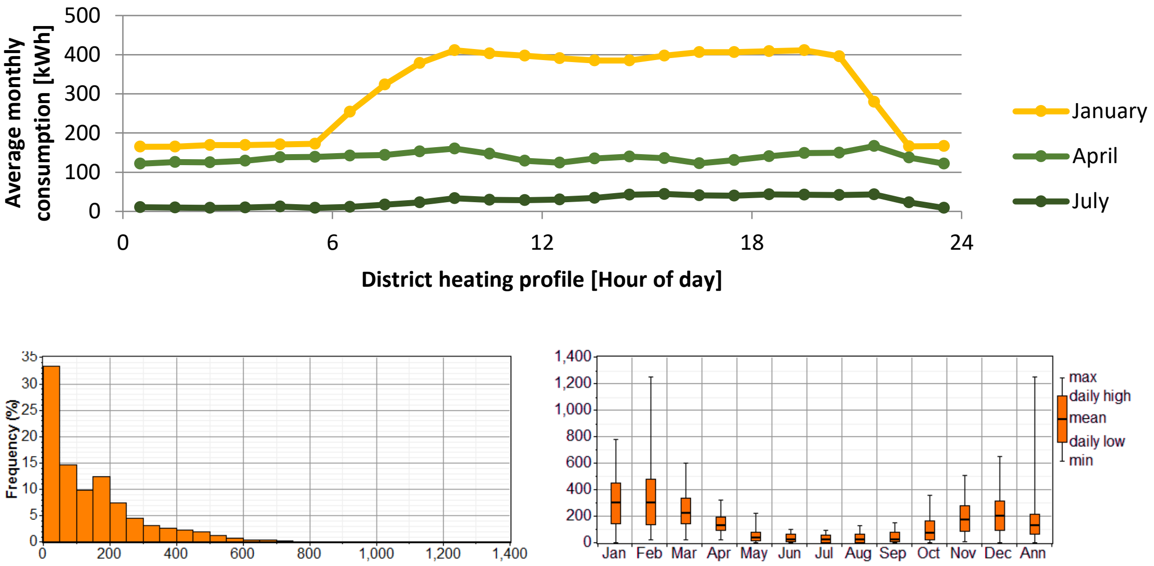


Figure 18. District heating profile based on recoded hourly data for the calibration year. Averages include days outside of operation like Sundays. Saturday's opening hours 09-20 differ from weekdays 09-21.

An analysis based on hourly data show that consumption vary more significantly between opening hours and hours outside of operation in the colder winter months than in the intermediate seasons. In summer district heating is used for tap hot water heating on, which mean that the district heating profile for July directly reflects the tap water demand, but accuracy is limited to the resolution of the data logger values (10 kWh steps). There are some peak hours in winter where draw is more than double of the daily average maximum consumption.

Shared electricity

Shared electricity (common area lighting, equipment, dual AWHP, cooling machines and central air handling units serving both tenants retail space and common areas) accounts for 1/3 of the total electricity consumption. The electricity demand profiles for each month indicates correlation with season as well as opening hours of the building. An analysis of shared electricity use on a monthly basis show that outside of operation hours there is little variation between minimum recordings and daily low averages (Figure 19, right). This means that electricity draw outside of operation remain on the same level from day to day as well as constant over the year. This is supported by the annual frequency distribution curve (Figure 19, left). More than 40 % of the annual time series fall within this range. Within operation electricity use is 2 to 5 times higher. The highest hourly consumption are reached usually in the opening and closing hours (i.e., 9am) during the winter months and after mid-day during the summer months.

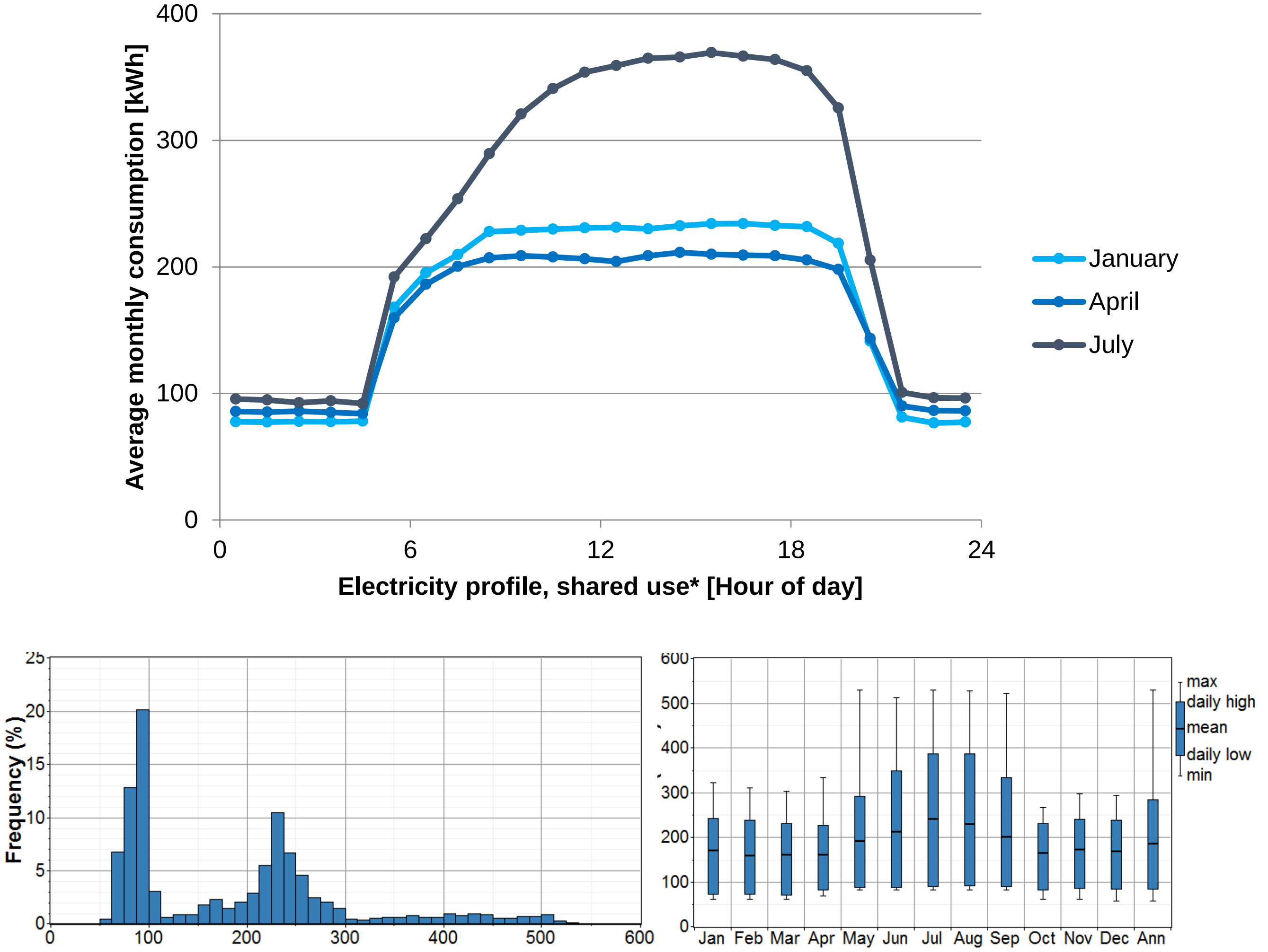


Figure 19. Shared electricity use (excluding tenants' electricity and outdoor lighting), frequency curve and monthly box plots. Averages include days outside of operation like Sundays. Saturday's opening hours differ from weekdays 09-21 (09-20).

The remaining share of electricity consumption (tenant's meters) is more constant over the year and largely governed by opening hours, as it is mainly tenants lighting and auxiliary electricity use in retail spaces (see chapter 5 for more details).

Space heating

The entrance is located to the south towards a large open parking lot. In the entrance area two smaller air curtains have been refitted above the lower entrance doors (ground floor), to limit the use of the larger air curtains (fan capacity 60 000 m³/h) which are located on both floors between entrance and the centre (Figure 20). This refitted air-curtain run in the heating season, limiting the internal draft exchange between the two entrances within the atrium. One tenant is located within the atrium on the outside of the large air curtains, opposite of the entrance on the ground floor.

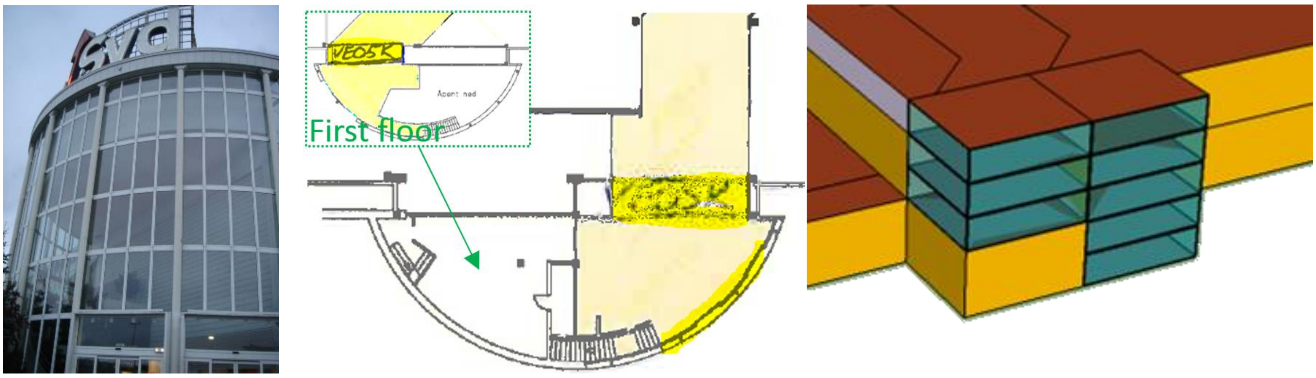


Figure 20. Photo of the facade (left), plan of the groundfloor outlining the air curtains in yellow, and the energy model representation of the multi story atrium entrance area (right).

Space cooling

The main cooling machine are dry coolers with a roof mounted unit which run in free cooling mode in the colder season (October to May). One tenant has their own HVAC system with a cooling plant which is in use (as part of an extension built 15 years ago housing a clothing store). In addition to the cooling machines which provide chill water, the AWHP are switched from heating to cooling mode in the mid-season.

The chill water loop is provided to tenants for space cooling (individual flow meters). Some, but not nearly all tenants are connected with their own cooling baffles and fan coils (See Figure 21– blue colour for space cooling). Because one tenant use the water for refrigeration purposes, the chill water run 24/7, but this may be changed soon after some in-store renovations.

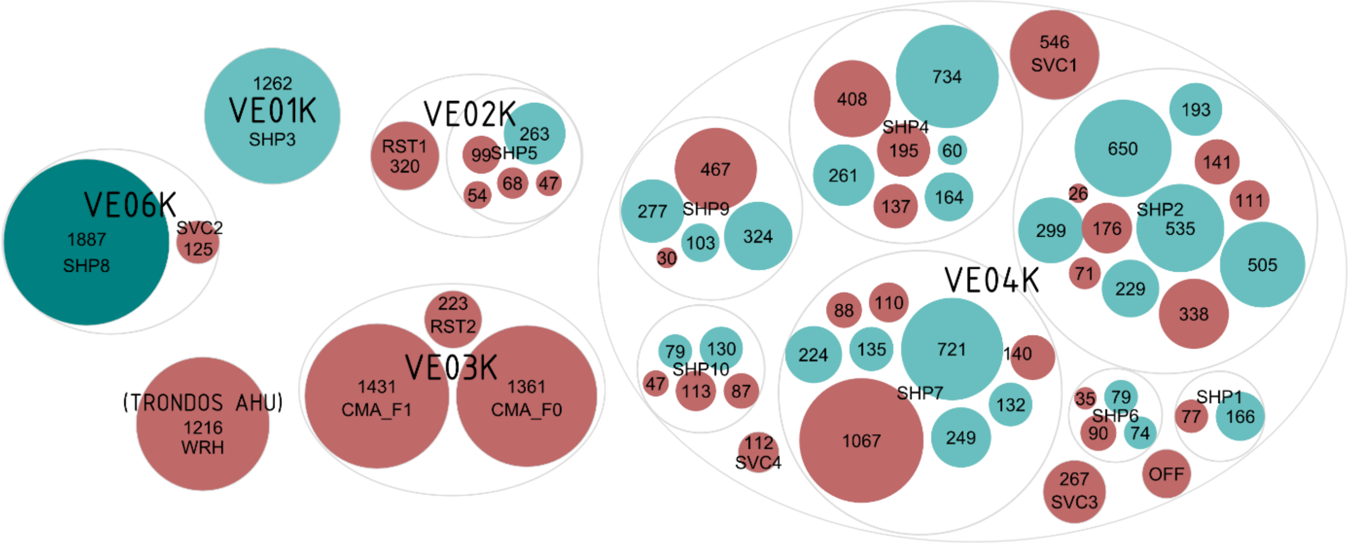


Figure 21. Bubble chart deceipting which tenants are currently connected to the chill water loop (blue color) and the zone in which they are located (SHP1-10) and the ventilation unit serving each zone (VExx). Numbers refer gross leasable area or net floor area for common areas (m²).

Natural ventilation

Originally radiant panels for cooling were installed in the common areas, but these are not in use, meaning that common areas are conditioned by ventilation air. Natural ventilation through openable windows in the central atrium skylights help vent out stale air in the summer. These windows are controlled by a propriety window ventilation system. This system has a rain sensor, temperature nodes and a wind velocity sensor which will close the windows when it rains, and when strong wind gusts occur. Complaints of drafts are sometimes an issue, but the system can also be overridden. The opening of the windows happen at intervals 10% 20 % ... 50 %, but the algorithm that controls this practice is propriety from the manufacturer.

Figure 22. Skylights in the central atrium and the cafeteria located on the mezzanine below. Openable windows are present on both sides (photo left and right).

Design

The centre was built in 1987 with an extension for 15 years ago (ca. 2000) to the right side in the drawings below. All the shops face the common areas which has a circular layout. This circulation space surrounds a central atrium with escalators and shops, cafeterias or restaurants located in two intermediate floors on a mezzanine adjacent to the atrium. A few shops has intermediate floors inside for retail space or storage purposes, but most span the full floor height of ca. 5,5 meter between the two main floors. Because of the available height ventilation ducts, and other infrastructure lay exposed in the ceiling.

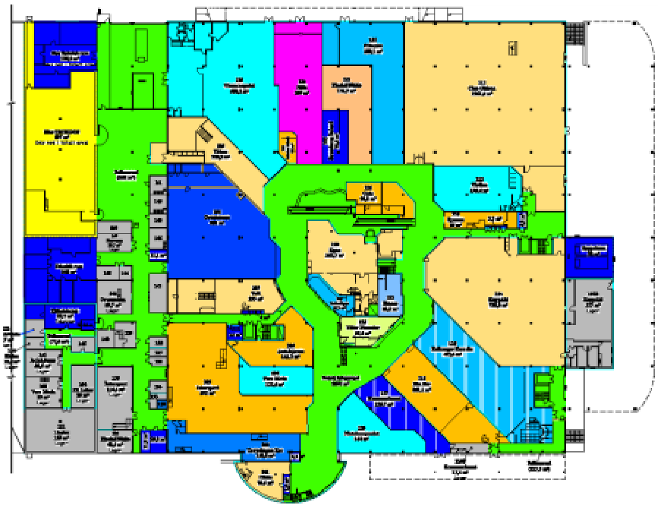


Figure 23. Ground floor plan of the centre

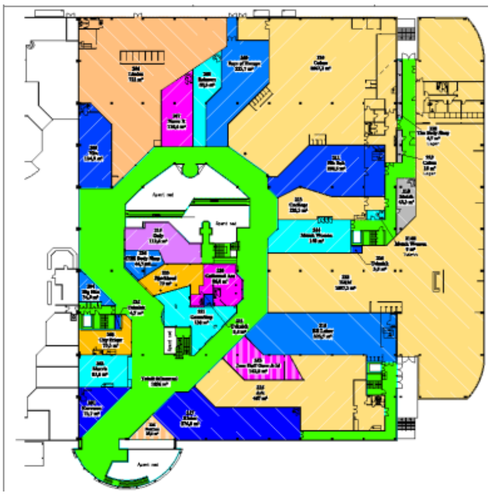


Figure 24. First floor plan of the modelled part

In the plan of the first floor (Figure 24) the part of the centre which is not modelled is outlined to the left with grey lines (no colour filling). There are no real separation between these two parts in in the common areas as indicated by the green void adjacent to the escalator in the atrium.

Location

See the map of Trondheim in Figure 25 that show City Syd with a green tag south of the city, whereas red tags mark community centres (convenience shopping) and additional green and blue tags marks other shopping centres in Trondheim.

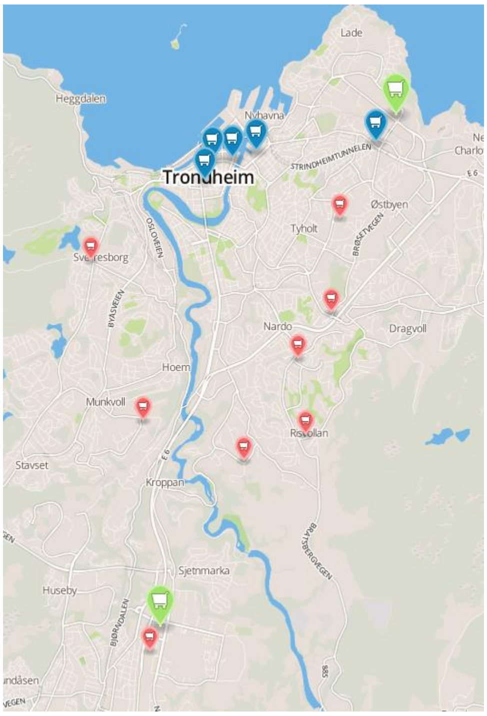


Figure 25. Map of shopping centres in Trondheim. Source: google maps

Building model

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

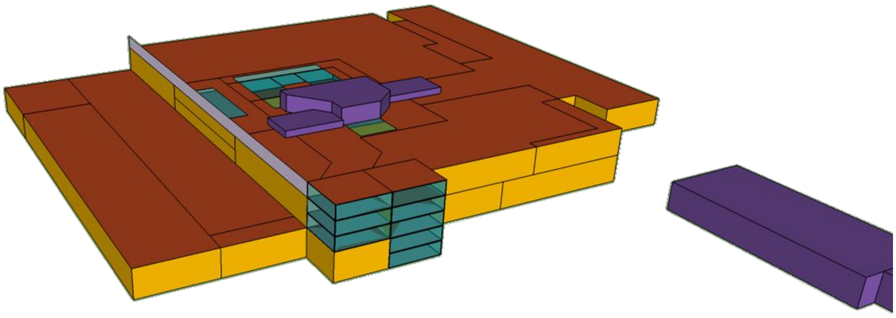


Figure 26. Building energy model in Sketchup (TRNSYS 3D plugin)

Weather file

Before we start defining the simulation boundary conditions, it is necessary a better insight of the weather files acquired from observation stations close to the location, or satellite images. The weather file provided in the project has lower average temperatures than the one which was initially constructed from several local providers including local temperature readings. However in order to use the same methodological approach for all the reference buildings in the CommONEnergy project, the weather file provided from EURAC is kept unmodified. The solar radiation data match in this weather file match well with global solar radiation measured at an agricultural metrological station located south of Trondheim (after using the Reindl conversion model to compute diffuse and direct radiation).

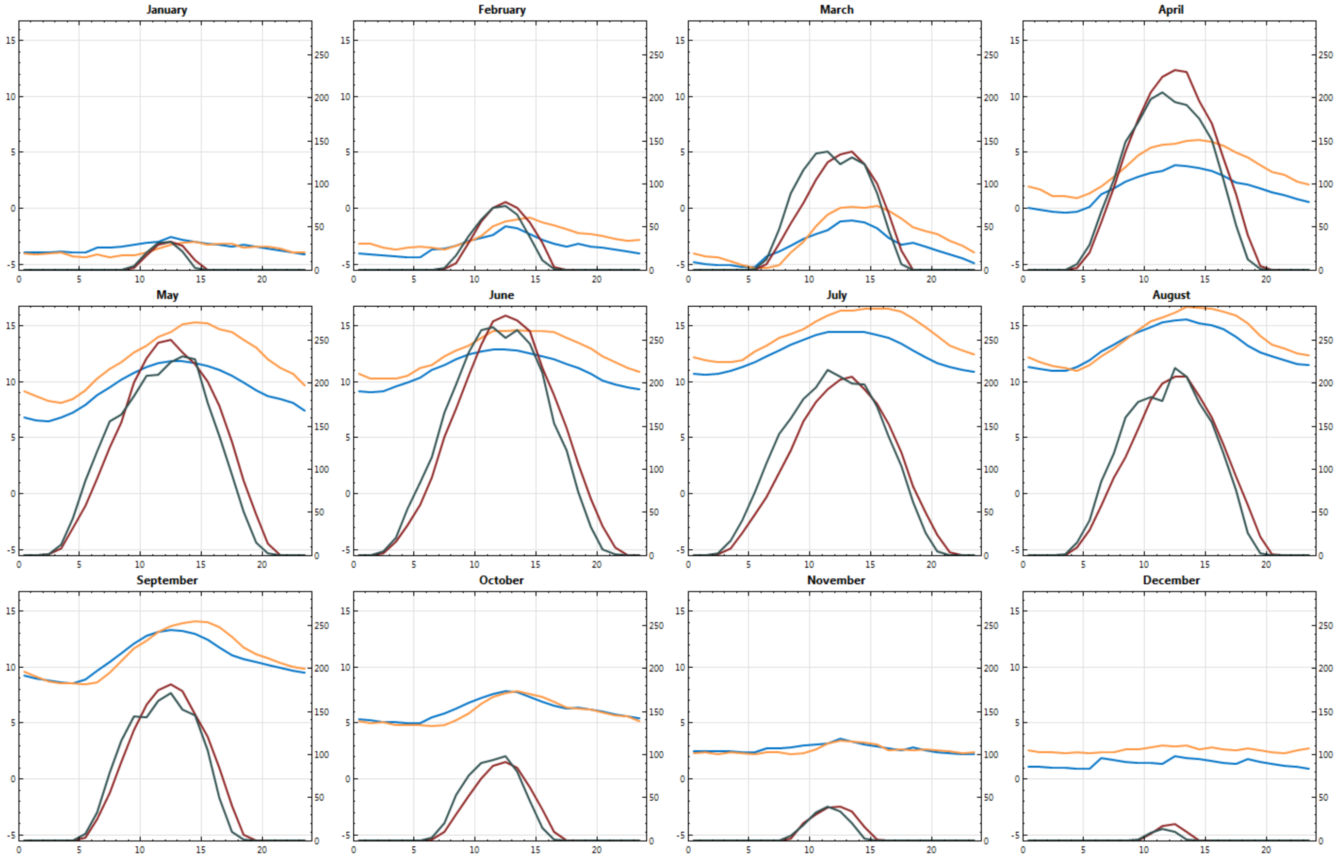


Figure 27. Month by month comparison of air temperature distributions (blue colour) and diffuse solar radiation (red colour) of the acquired weather dataset for Trondheim in 2013 and a local dataset manually constructed from Voll meteorological station (orange colour, ref: eklima.no) and solar radiation from agricultural weather station Shettlein, south of the city (green colour, ref: lmt.bioforsk.no).

Figure 27 and Figure 28 show a comparison of the same weather file acquired within the project (dark red and blue colours) and a weather file for a typical year in Trondheim (light red and green colours). Average diffuse solar radiation is close to the typical year, temperatures are also here lower in the project file.

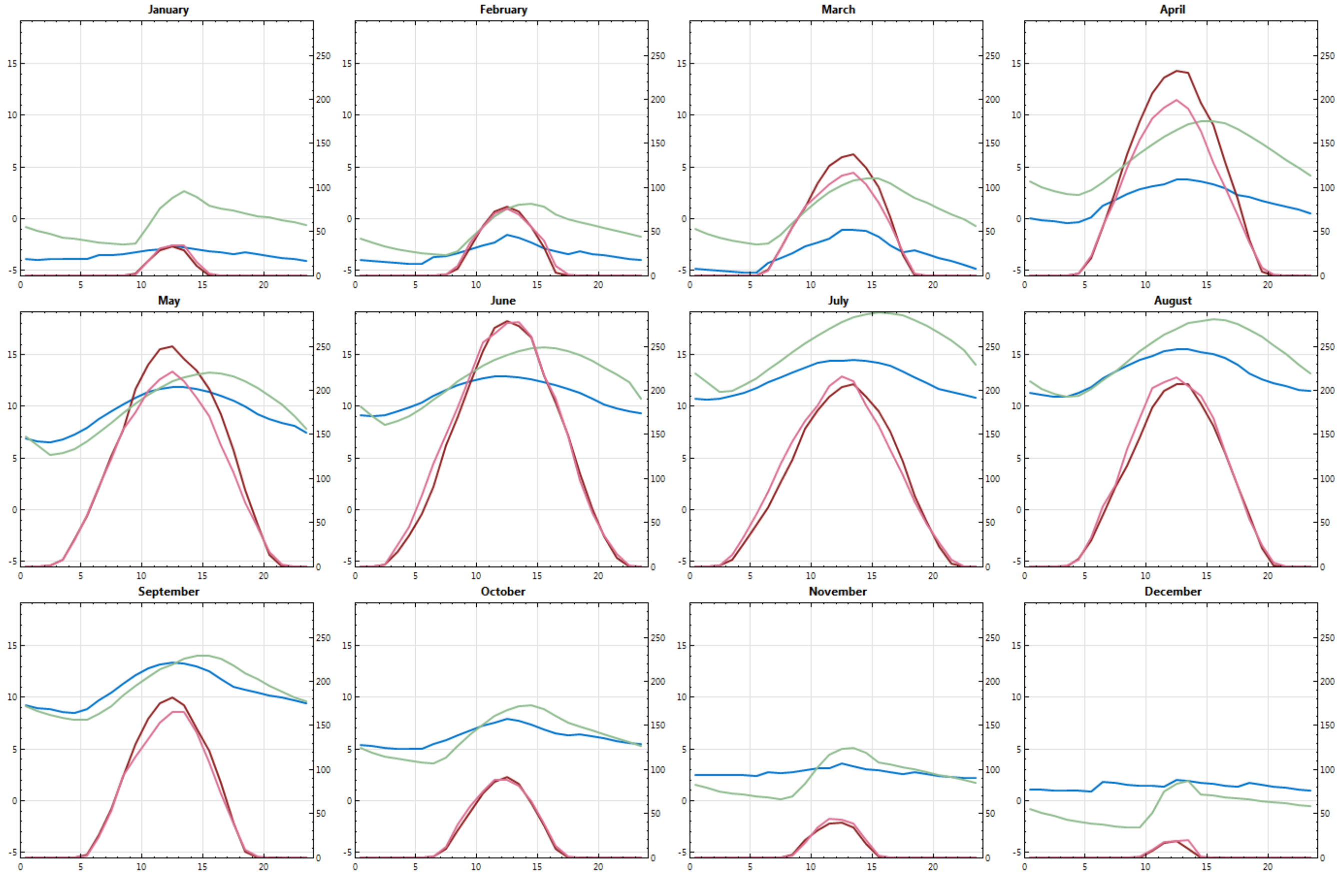


Figure 28. Comparison of air temperature distributions and diffuse solar between an average year and the weather file used for the location of Trondheim in 2013 (Norway).

Zoning

The building model is divided into 24 thermal zones according to space functions (internal gains level), HVAC systems, orientation and height. In the final energy model, individual shop units were grouped into thermal zones, following the IME methodology developed within the project. This mean that adjacent shops with similar properties and HVAC systems are merged (Figure 29). The internal room height is approximately 5.4 - 6 m in most of the centre.

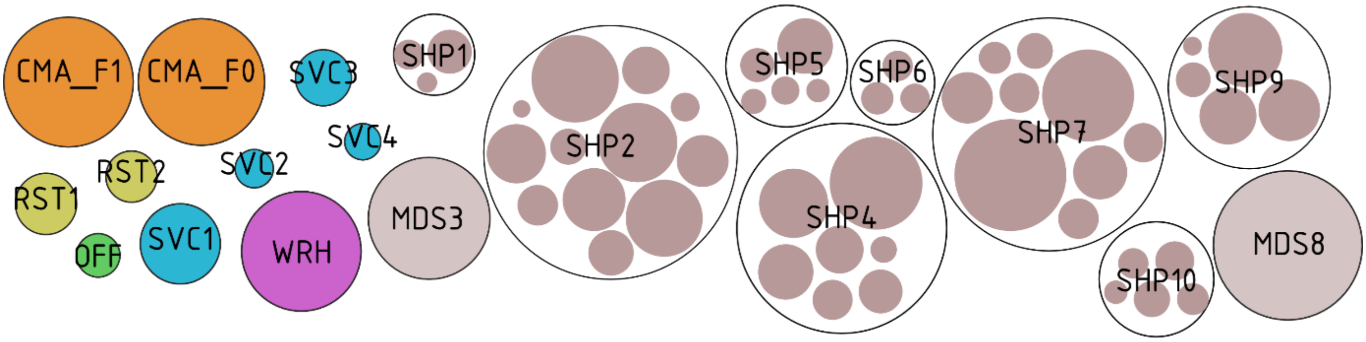


Figure 29. Bubble chart diagram of the areas, grey are gross leasable area of each shop unit, and the black circles show which units are combined into thermal zones (and their designated names in TRNSYS).

Thermal stratification in atriums and entrances

In order to account, although in a simplified way, for thermal stratification, all the atriums (4 in total) are subdivided into 3 m tall nodes. These are effectively child zones with individual air temperatures and characteristics, but radiation and airflow is distributed within each main zone. Taking thermal stratification into account bring the total number of thermal zones to 31. In order to simplify the model slightly to staircases which connects the two floors are omitted from the model. The location of atriums and skylights are displayed in Figure 30.

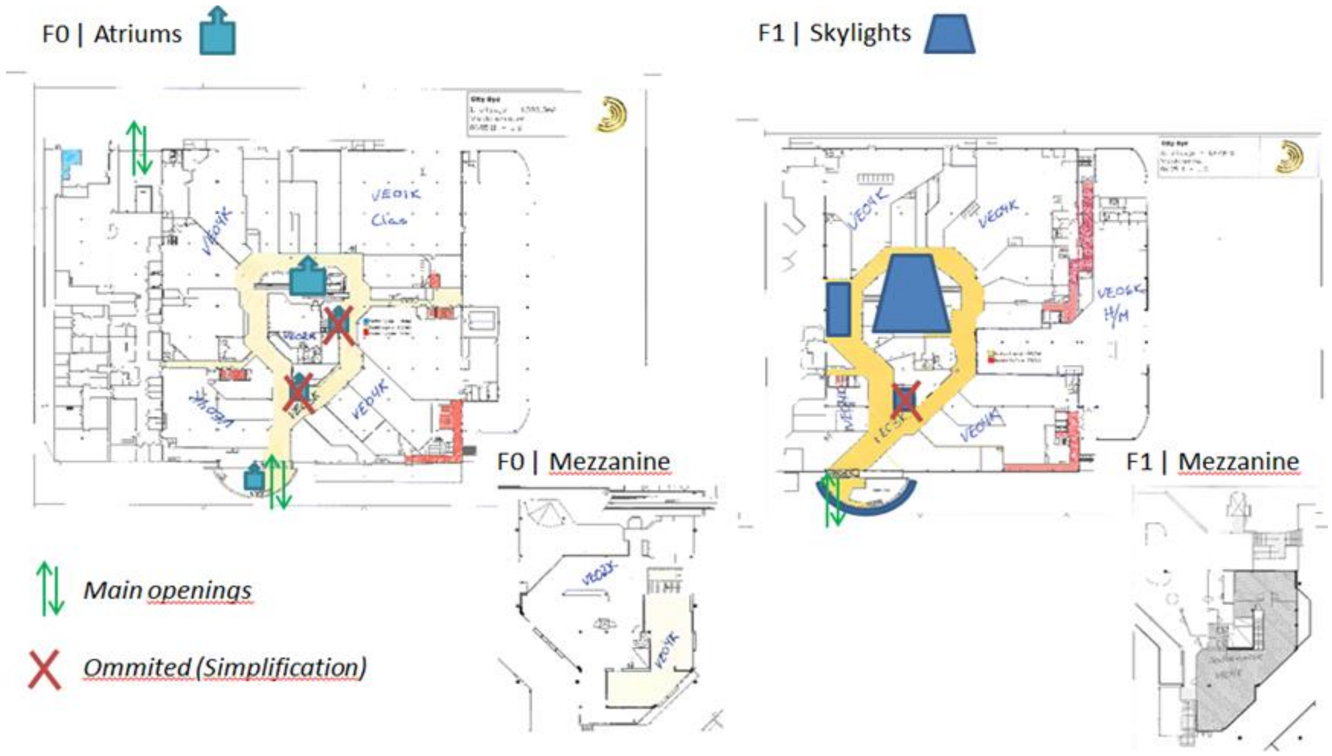


Figure 30. Location of atriums and skylights modelled in the

Zonal division of space in the energy model

Sometimes shops which are not necessarily located next to each other may also share characteristics, for example the surface area exposed to the outdoor environment, location and type of shop. In a reduction process, this give reason to combine spaces which are not physically adjacent. However, because it was decided to build a 3D representation of the centre, it was necessary to have as much as 10 unique zones for shops, besides 2 for restaurants and 4 zones for service areas. Figure 31 to Figure 33 show the geometrical layout of the simplified energy model.

If one were to simplify the model by reducing the amount of thermal zones, we suggest to merge zones (or individual shops) that share location and boundary conditions. I.e. all shops located close to the entrance is grouped into one zone, shops with no external facades are merged into another, shops with 2 external facades or more are merged and so on.

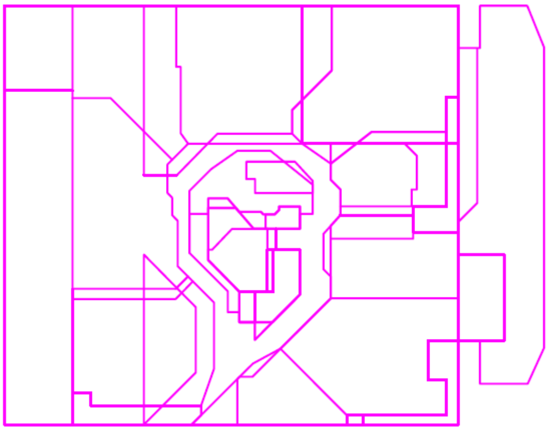


Figure 31. First zoning attempt with outlines of both floors laid out on top of each other. Not implemented into the thermal model, see Fig, 17.

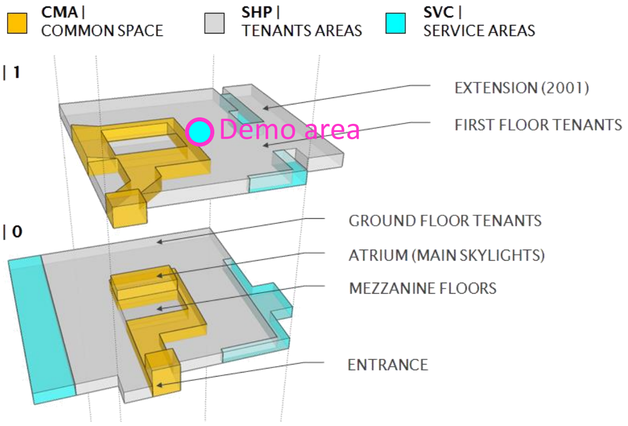


Figure 126. Diagram of the simplified 3D energy model illustrating the positioning of common, tenant and service areas. See Figure 17 for details sub-division of zones.

Zonal heat balances and aspects affecting temperatures within the centre

Even though the internal divisions are simplified from the actual floor plan, the gross leasable unit and external facade areas are respected. This simplification means that units may share less, little or too much internal walls with adjacent zones. In relation to establishing the magnitude of the heat transmission between the zones through internal partitions, the air exchange between units are a significant part of heat exchange occurring between zones, which has consequences for estimating heating, cooling and temperature distribution within the centre.

In the baseline model air exchange is not considered between zones. As a result, temperatures may vary greatly between the zones and that heating and cooling may occur at the same time in the simulation. Heat transmission (conduction) through internal walls, will account for some of the exchange of heat between zones, evening out temperatures. By modelling internal partitions with poor insulation level, this effect may also compensate for the heat exchange which could be modelled through air exchange paths. However, other physical effects normally cause temperature difference between parts of a centre and may lead to heating and cooling at the same time. The dominant airflow direction between zones, placement of ventilation inlets and outlets, thermostat placement and HVAC control algorithms, as well as the effect of additional partition walls between zones.

To see that these effects are within reason it is important to analyse temperatures as well as heat transfer and infiltration during validation. Therefore the modelling layout illustrated below was used as a basis for heat maps, to investigate the heat balances and temperatures by visual comparison.

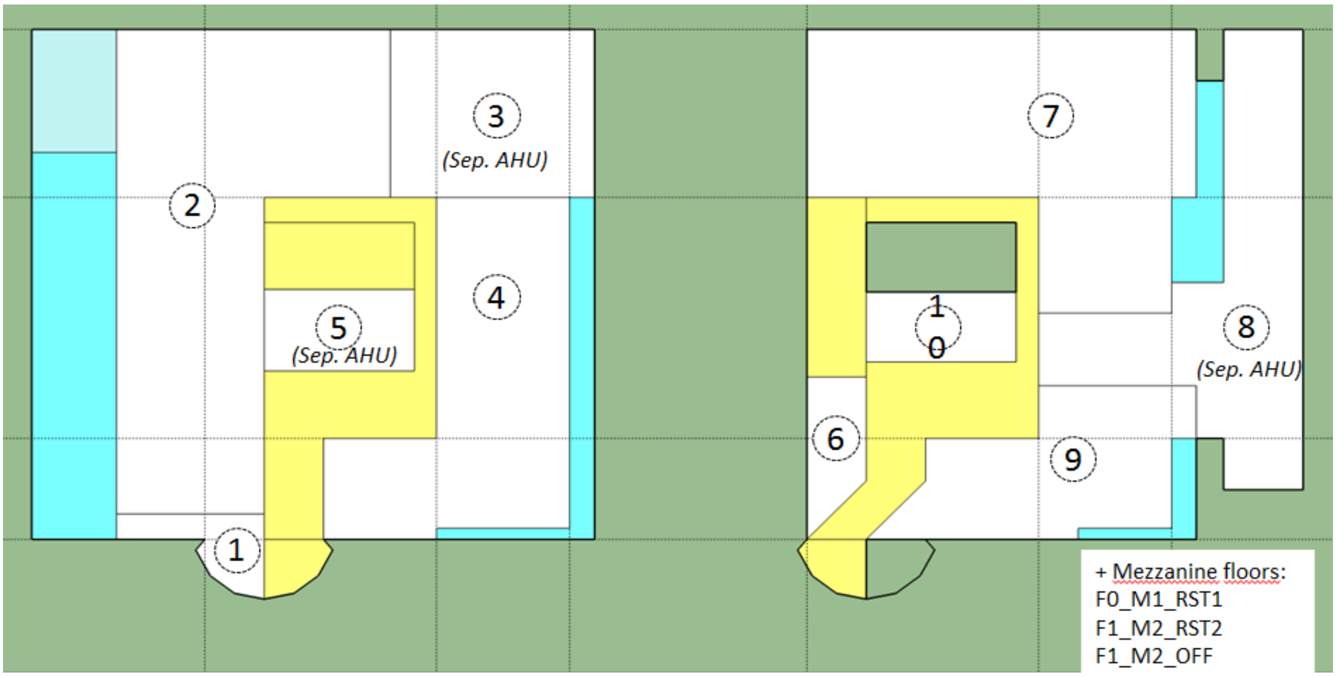


Figure 33. Diagram showing the simplified modelling layout still respecting the external facades and internal floor area of each shop/retail zone. This layout is also used for heat maps (see next chapter).

Zoning labelling and table of descriptions

Table 6 reports the Zone ID and their main geometry dimensions as well as the air node capacitance set. Zone ID is structured as following:

1. building level:
   F0 = ground floor
   F1 = first floor
2. orientation:
   E = east
   SE = southeast
   S = south
   SW = southwest
   W = west
   N = north
   NE = northeast
   M = mezzanine / middle
3. function:
   SHP = zone consisting of multiple shops and retail units
   CMA = common areas
   RST = restaurant, cafeterias
   SVC = service rooms
   MDS = larger shop with separate air handling units, and/or cooling plant.
   PRK = cargo loading bay area (indoor parking)

For example zone ID F0_M_CMA refers to the common area (CMA) located at ground floor (F0) and oriented towards the middle of the centre (M) – no external facades to relate orientation to.

Table 6. Zone data summary.

#	ZONE ID	Area $[m^2]$	Height [m]	Volume $[m^3]$	Airnode cap. [kJ/K]	Ventilation AHU [VE...]	Space H/C (% cooled)	Zone description
1	F0_N_PRK	308	6	1 696	2 035	AEROTEMPERE	Air curtain	*Cargo port*
2	F0_W_WRH	1 217	6	6 692	8 030	(-)	-	*Main storage space*
3	F0_M_CMA1	891	6	4 898	5 878	VE03	-	*Circulation space*
4	F0_A_SE_CMA2	109	15	1 523	1 828	VE05	Air curtains	*Entrance (2 story)*
5	F0_A_M_CMA3	354	12	4 242	5 090	VE03	-	*2 story Atrium*
6	F0_SE_SVC	546	6	3 001	3 602	VE04	-	*Storage space*
7	F1_M_CMA1	939	6	5 163	6 195	VE03	-	*Circulation space*
8	F1_A_SW_CMA2	109	9	870	1 044	VE05	Air curtains	*Entrance (1,5 story)*
9	F1_A_M_CMA4	376	6	2 256	2 707	VE03	-	*Atrium (1 story)*
10	F1_N_SVC	125	6	689	827	VE06	-	*Storage space*
11	F1_SE_SVC	267	6	1 466	1 759	VE04	-	*Storage space*
12	F0_SW_SHP1	241	6	1 333	1 600	VE04	C (68 %)	*2 Shops/retail zone*
13	F0_N_SHP2	3 277	6	18 011	21 614	VE04	C (74 %)	12 Shops/retail zone
14	F0_NE_MDS3	1 210	6	6 938	8 326	VE01	C (100 %)	Medium size store
15	F0_S_SHP4	1 959	6	10 772	12 927	VE04	C (62 %)	7 Shops/retail zone
16	F0_M_SHP5	432	3	1 187	1 425	VE02	C (50 %)	5 Shops/retail zone
17	F1_M1_RST1	432	3	1 187	1 425	VE02/VE04	-	Restaurant
18	F1_M_SHP6	279	6	1 526	1 832	VE04	C (55 %)	4 Shops/retail zone
19	F1_N_SHP7	2 854	6	15 766	18 919	VE04	C (51 %)	9 Shops/retail zone
20	F1_E_MDS8	1 872	6	10 380	12 456	VE06	C (100 %)	Medium size store
21	F1_S_SHP9	1 195	6	6 599	7 919	VE04	C (59 %)	5 Shops/retail zone
22	F1_M_SHP10	456	3	1 252	1 502	VE04	C (46 %)	5 Shops/retail zone
23	F1_M^2_RST2	223	3	613	736	VE02/VE03	-	Cafeteria
24	F1_M^2_OFF	161	3	443	531	VE04	-	Office administration

Building envelope

Table 7 accounts for the building constructions as implemented in the model. A couple of shops have refitted newer ventilation systems, and the roof has been retrofitted with twice the original insulation. Therefore, several performance levels are applied.

Table 7. Thermal properties used the building model coloured red, and additional performance levels for reference. The centre was completed in 1987, and in year 2000 an extension was made.

Building codes	**TEK-1985**	**TEK-1987**	**TEK-1997**	**TEK-10 (2010)**
Description	**Building codes as built to std. 1985**	**Building codes year of completion**	**Redevelopment in 2000 (extension)**	**Current min. std. (for reference only)**
U-value ext. wall (W/(m^2K)	0.45	0.30	0.22 (extension)	0.18
U-value roof (W/(m^2K)	0.23	0.23	0.15 (entire roof. retrofitted w/30cm)	0.13
U-value floor (W/(m^2K)	0.30 (not taking into ground resistance).	0.30	0.15 (extension. exposed to air)	0.15
U-value windows / doors (W/(m^2K)	*to be included in the facade.	2.40	1.6 - 2,0	1,2
U-value doors / ports (W/(m^2K)	2.0	2.0	2,0	1,2
air tightness (ach)	*Typical: 3.0 ach*		3,0	2,0
Heat recovery (%)	*Varies: 50 – 65 %*		Typical 65 %	80 %
specific fan power (kW/(m^3/s))	*Typical: 3.0*			2,0/1,0

Regime data

Heating and cooling setpoints

The heating demand of the centre has been calculated by imposing a set point temperature of 20°C in common areas and 18°C in service areas. The cooling demand of has been calculated by imposing a set point temperature of 26°C during weekdays (Monday to Saturday) in shop zones. No additional air humidification is considered during the winter time, since this is not the case (see appendix for AHU system diagrams).

Infiltration

The infiltration rates are set to a constant value of 0.105 ACH both in retail zone of the model (shops, restaurants and offices). In common areas infiltration is set 8 times higher to 0.84 ACH outside if operation and 1.84 ACH in operation.

Simple implementation of natural ventilation in the base case model

In summer infiltration is increased in common areas to 5.84 ACH whenever temperatures exceed 25 'C within opening hours, mimicking the natural ventilation (controllers in the skylight windows). When temperatures

Ventilation

Ventilation rates are set according to design capacities, heat recovery efficiency is set according to the type of unit and performance was spot checked with readings from the building energy management system.

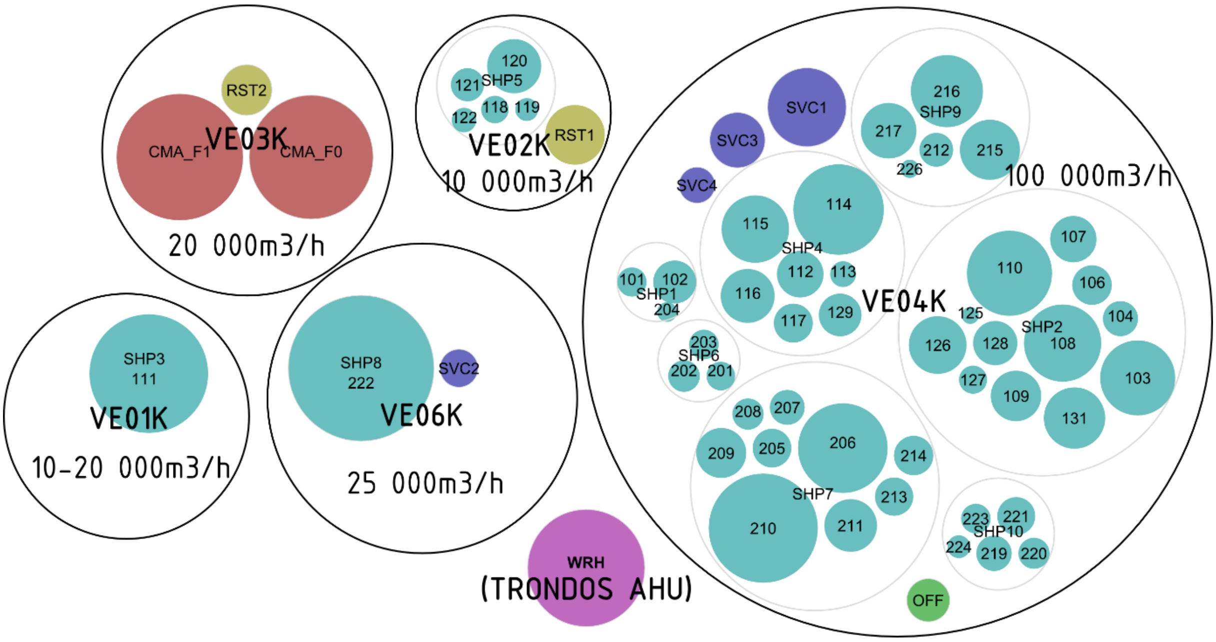


Figure 128. Ventilation rates are indicated by large black rings, while coloured bubbles refer to the floor area of each space (ventilation rates are averages per floor area in each zone per air handling unit).

Table 8. List of ventilation units

	Description	Design capacity	Heat recovery (HR)	Typical HR eff.
VE01K	Single shop (MDS3)	20 000 m³/h	Thermal rotary wheel	70 %
VE02K	Mezzanine retailers	10 000 m³/h	Run around water coil	50 %
VE03K	Common areas	20 000 m³/h	Thermal rotary wheel	70 %
VE04K	Most shops and retail	100 000 m³/h	Run around water coil	50 %
VE05K	Large air curtains	75 000 m³/h	Recirculation	-
VE06K	Single shop (MDS8)	25 000 m³/h	Plate heat exchanger	65 %
	Kitchen exhausts	Unknown	None	-

Limitations in the baseline TRNSYS model

In the baseline model the inlet air temperature is assumed to be equal to the outdoor air temperature in line with the integrated modelling environment. Heat recovery is fixed to a constant efficiency applying a reduction factor to the ventilation mass flow definition, and set specific for each zone to the efficiency of the air handling unit which serves the particular space (VE01-06).

Occupancy

The internal gain due to the presence of persons has been quantified by considering a specific density of 0.14 person/m². The EN ISO 7730 standard recommends to consider a total heat flux of 185 W/person for retail store case where people are standing and performing light work. This value takes into account sensible (90 W/person) and latent gains (95 W/person).

Occupancy loads are considered for shop, common areas and restaurant zones from 6am to 4pm during weekdays (Monday to Saturday). The daily occupancy schedule for the each zone typology is reported in Figure 129.

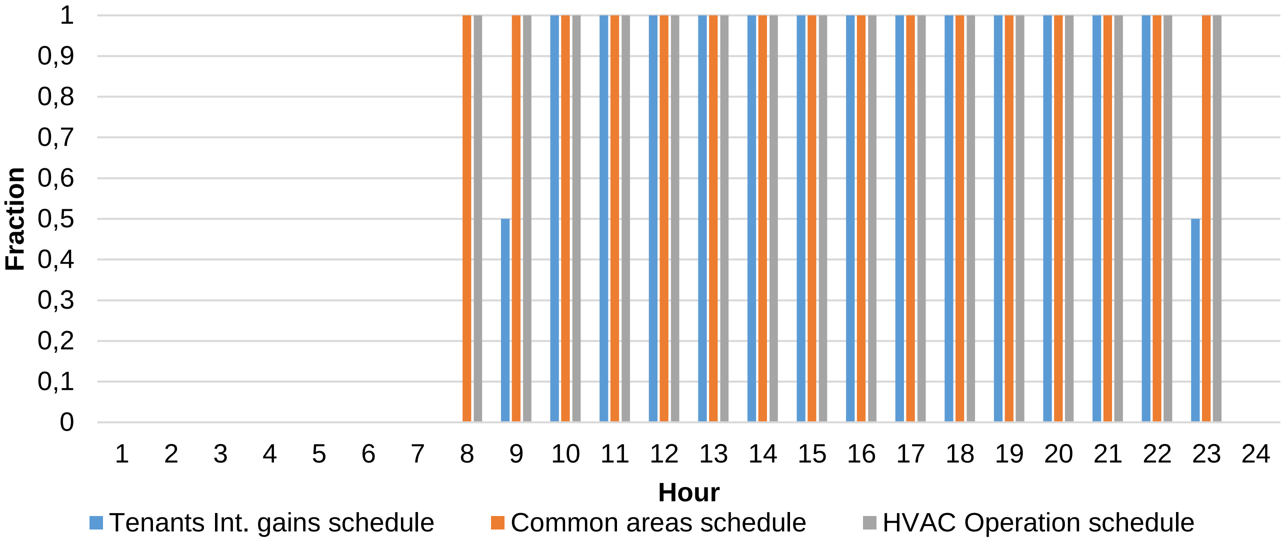


Figure 129. Occupancy schedule for shop (SCH_SHP_PER), common areas (SCH_CMA_PER) and restaurant zones (SCH_RST_PER).

Lighting

We set a specific internal gain for lighting of 15 W/m² in the shop zones, 14 W/m² in the common areas and the restaurant, and 2 W/m² in the parking zone. This value has been divided between 0.4 convective and 0.6 radiative fractions.

The daily lighting operation schedule for the each zone typology is reported in Figure 129.

Appliances

We set a specific internal gain for appliances of 7 W/m² in shops, restaurant, service, technical rooms and parking zone. As shown in the graph in Figure 129, shops and restaurant gains are set constant throughout the whole day. Service and technical rooms and parking zone loads are on only during occupied hours.

Simulation settings

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoints all the time. System efficiencies were added in the further simulations, depending on system complexity.

Table 9. Simulation settings

Simulation settings	
Timestep	15 min
Simulation start	January 1st
Simulation stop	December 31st
Preconditioning period	1 month
Simulation mode	Unlimited power

	Common areas		Shops		Restaurants		Service		Warehouse		Office	
	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule
People density [pers/m²]	0.14	08:30 – 21:30	0.14	09:00 – 21:00	0.14	09:00 – 21:00	0.14	07:00 – 22:00	0.14	09:00 – 21:00	0.14	09:00 – 21:00
Lighting density [W/m²] [a]	14	08:30 – 21:30	35	09:00 – 21:00	35	09:00 – 21:00	14	07:00 – 22:00	14	09:00 – 21:00	35	09:00 – 21:00
Equipment [W/m²]	7	08:30 – 21:30	10	09:00 – 21:00	10	09:00 – 21:00	7	07:00 – 22:00	10	09:00 – 21:00	10	09:00 – 21:00
	7	21:30 – 08:30	0	21:00 – 09:00	0	21:00 – 09:00	7	22:00 – 07:00	0	21:00 – 09:00	0	21:00 – 09:00
Heating setpoint temperature [°C]	20	07:00 – 22:00	20	07:00 – 22:00	20	07:00 – 22:00	20	07:00 – 22:00	20	07:00 – 22:00	20	07:00 – 22:00
Heating setback temperature [°C]	15	22:00 – 07:00	15	22:00 – 07:00	15	22:00 – 07:00	15	22:00 – 07:00	15	22:00 – 07:00	15	22:00 – 07:00
Cooling setpoint temperature [°C]	26	07:00 – 22:00	26	07:00 – 22:00	26	07:00 – 22:00	26	07:00 – 22:00	26	07:00 – 22:00	26	07:00 – 22:00
Cooling setback temperature [°C]	-	-		-		-		-		-		-
Ventilation rates [b] [m³/(h m²)]	7	07:00 – 22:00	9	07:00 – 22:00	7	07:00 – 22:00	9	07:00 – 22:00	2.5	07:00 – 22:00	9	07:00 – 22:00
Infiltration rates [ach][c]	0.84	00:00 – 24:00	0.105	00:00 – 24:00	0.105	00:00 – 24:00	0.105	00:00 – 24:00	0.105	00:00 – 24:00	0.105	00:00 – 24:00

a: Different values for outside operation to match measured data.
b: Different ventilation rates, see Fig. 2
c: In common areas infiltration is set 8 times higher to 0,84 ACH outside if operation and 1,84 ACH in operation. In summer infiltration is increased in common areas to 5,84 ACH whenever temperatures exceed 25 'C within opening hours, mimicking the natural ventilation (controllers in the skylight windows).

Baseline outputs (validation)

The following diagrams show the measured and simulated values of the model.

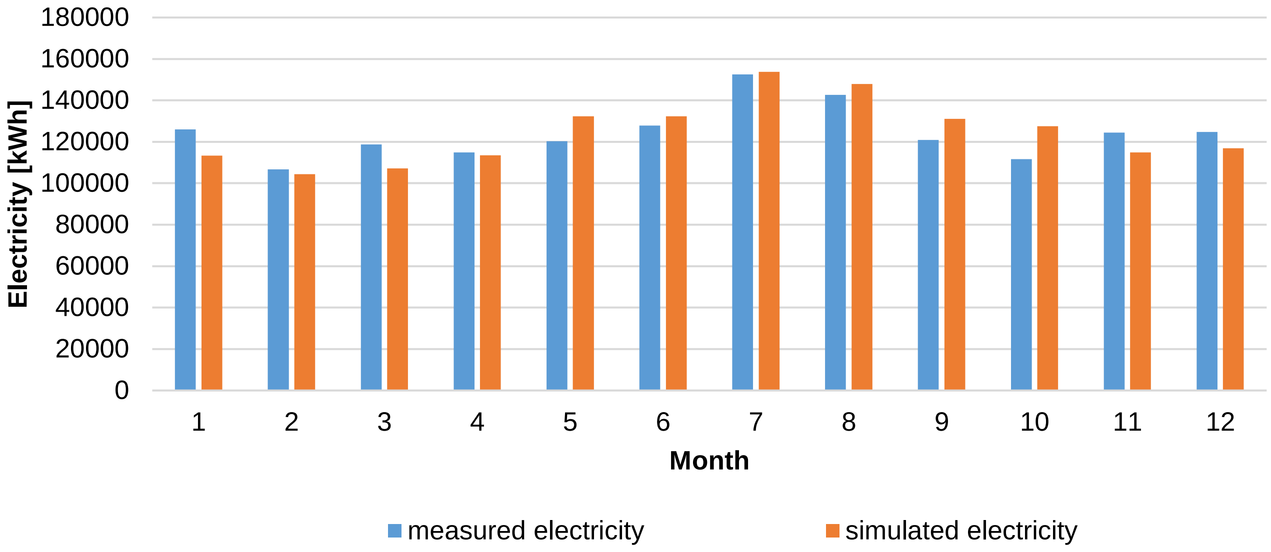


Figure 130. Measured and simulated monthly electricity

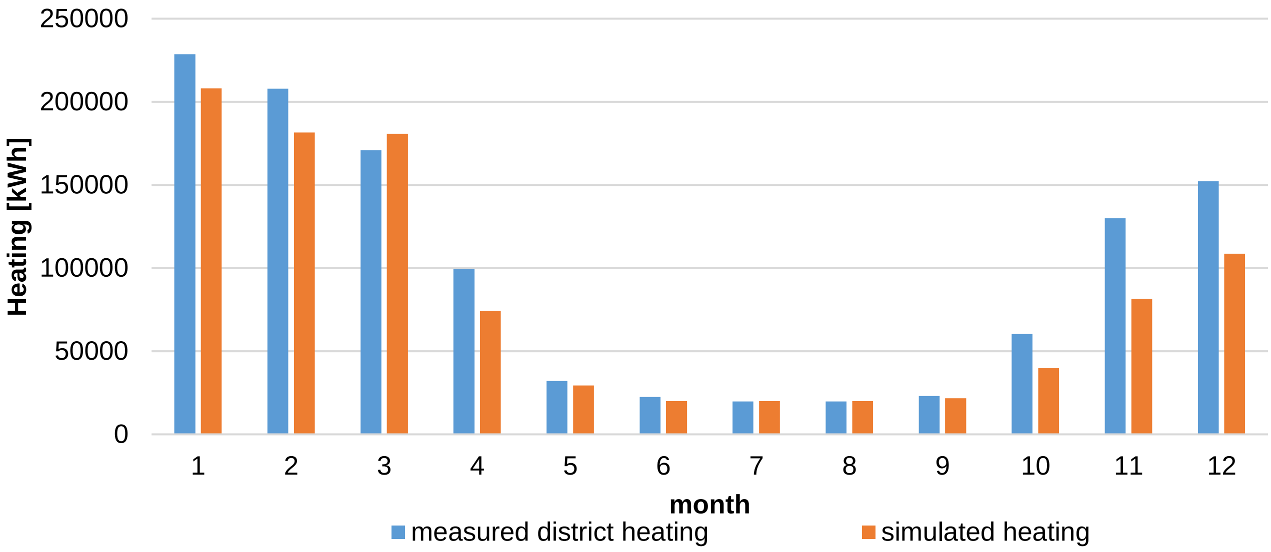


Figure 131. Measured and simulated monthly heating

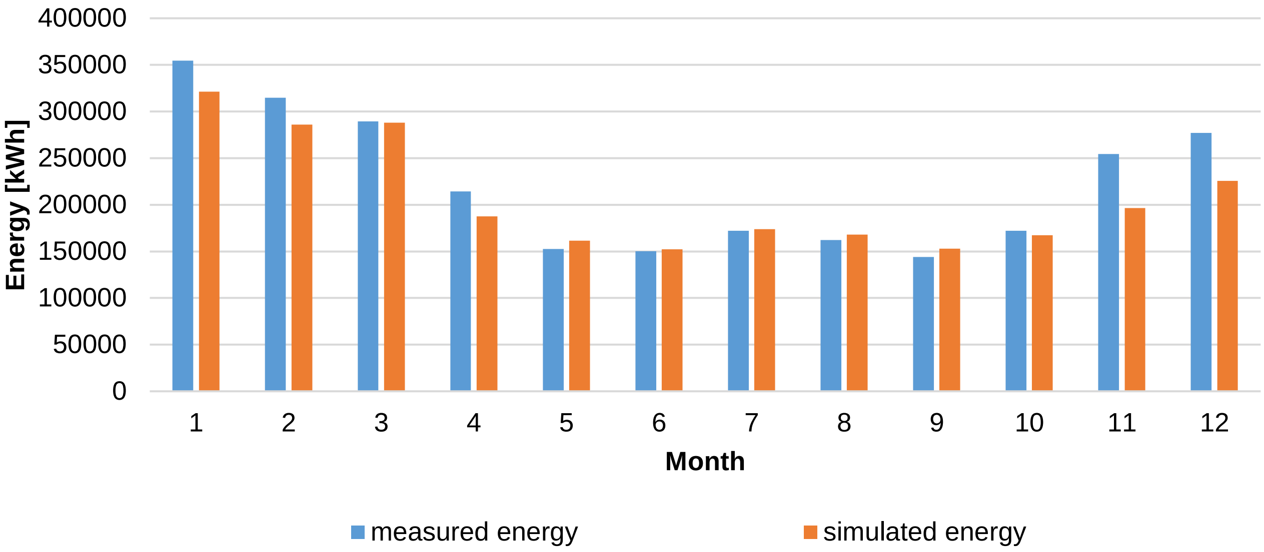


Figure 132. Measured and simulated monthly energy

Thermal comfort analysis according to Fanger model

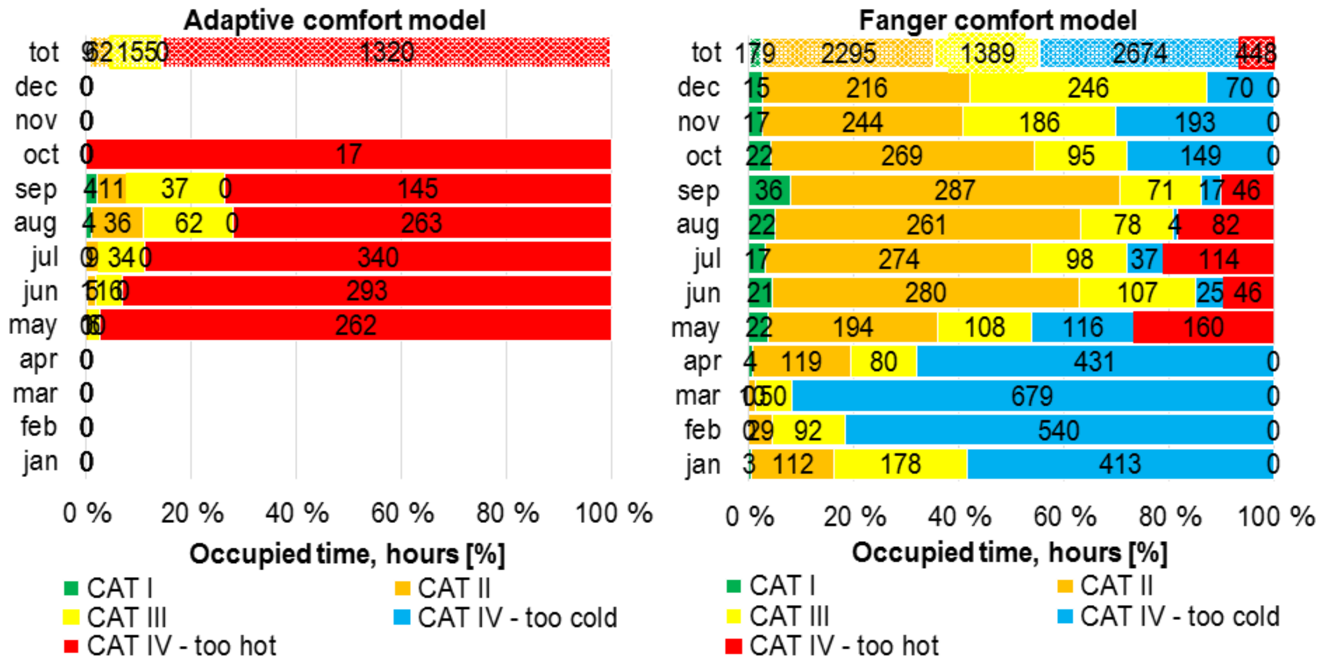


Figure 133. Number of hours when indoor temperature conditions are within Fanger comfort model categories.
RST1 Cafeteria located below the skylight in the atrium – (upmost floor of the mezzanine). Ideal heating + window ventilation when temperatures exceed 25 'C, until they are below 22 'C (only activated in opening hours).

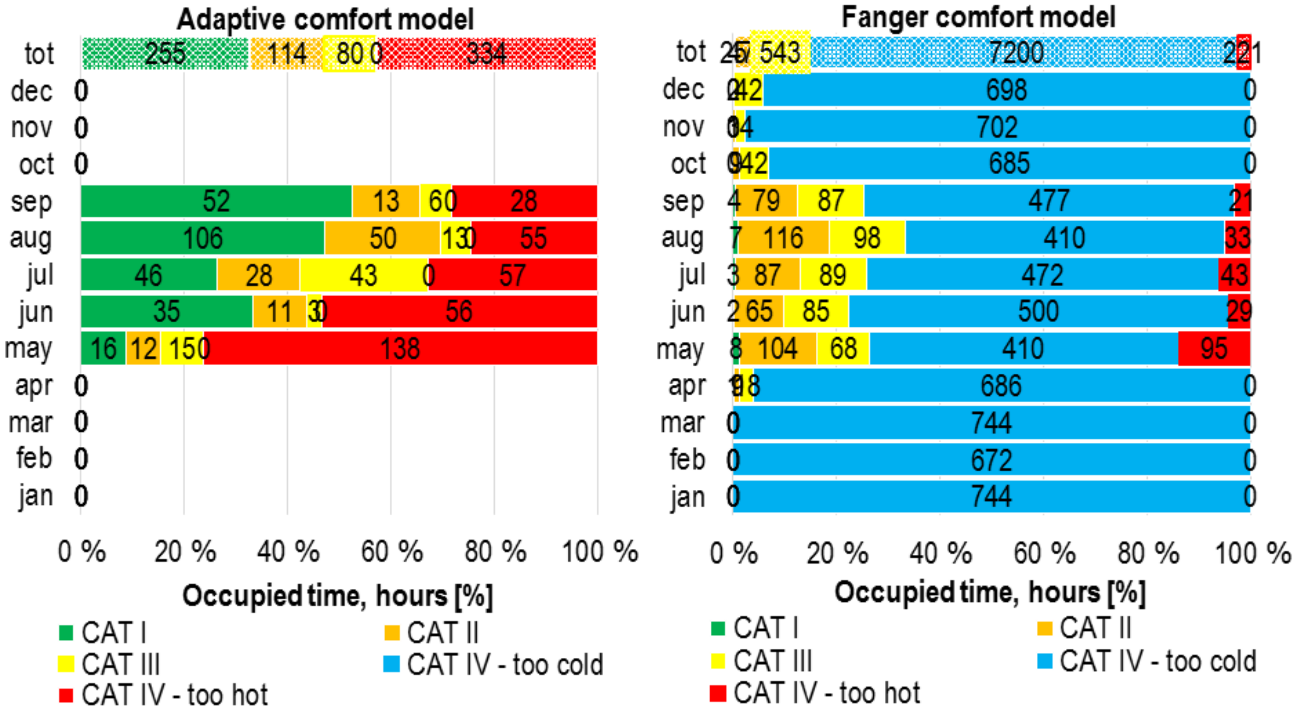


Figure 134. Number of hours when indoor temperature conditions are within Fanger comfort model categories. CMA1 Common areas. Ideal heating + window ventilation

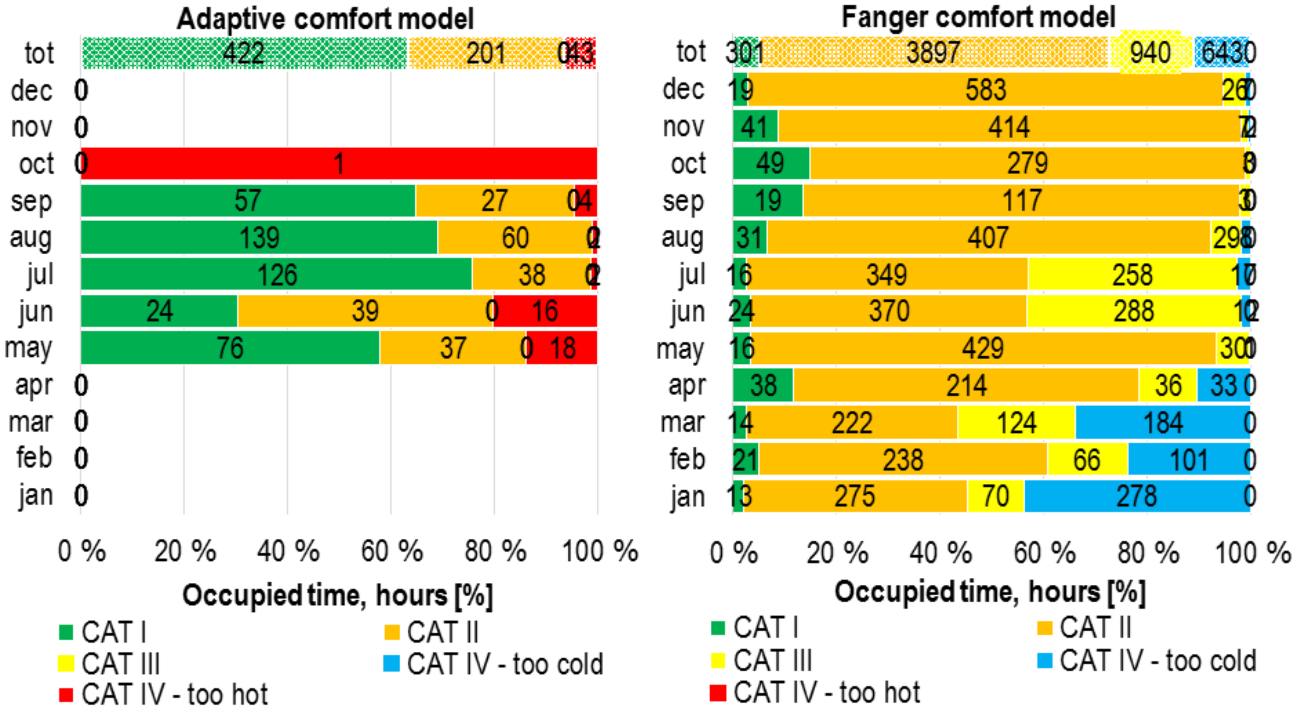


Figure 135. Number of hours when indoor temperature conditions are within Fanger comfort model categories. SHP9 Demo space area. Ideal heating and cooling.

Solution set description

The solution set here described is balanced on the specific needs of the City Syd demo case building and the climate conditions of Trondheim. Therefore, its replication in other climates or other buildings need to be further investigated.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decide to reduce lighting power density **(solution 1)**. Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need by 84%, but increasing the heating demand.

The installation of energy efficient appliances is seen as an important further step to reduce energy use in the shopping centre (**solution 2**). Further, exploitation of natural ventilation within common areas improvements of the ventilation including airtightness **(solution 3)** is suggested in order to reduce further cooling but also ventilation energy need and to reduce heating need. Existing openings, designed for smoke ventilation can also help vent out stale air in the hot days. The connection of opening control to the iBEMS and the integration of inverters automated by the iBEMS would allow to switch off the mechanical ventilation and cooling in the common areas when natural ventilation is activated and to introduce a more sophisticated control strategy. In addition, replacing the AHUs including heat recovery systems with high efficient systems is proposed. It is further proposed to reduce heating demand by roof insulation, changing windows and insulating the delivery entrance area **(solution 4)**.

Finally, the installation of PV plant (750 kWp) on the roof **(solution 5)** will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. Table 10 provides an overview of the selected solutions. Each solution is described in more details below.

Table 10. Summary of solutions

Solutions		measures	Impact on energy	Comfort
1	**Lighting**	Various measures for CMA, shops, restaurants, service areas	x	X
2	**Appliances**	Energy efficient appliances, escalators etc.	x	
3	**Ventilation**	Natural ventilation in summer, better infiltration of common areas by new entrances, new AHU and heat exchangers	X	x
4	**Insulation**	Insulation of roof, (walls), new efficient windows, and reduced infiltration by new delivery door.	x	X
5	**RES – PV**	6750m² PV plant (750kWp)	x	

Solution 1: Efficient lighting system and controls

Objective	To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off

Description

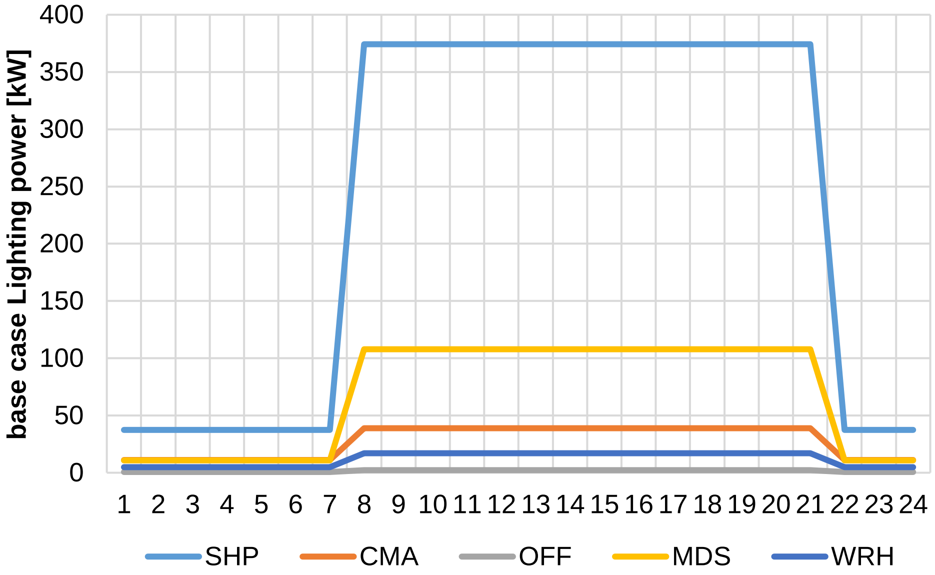
Lighting power density is reduced down to 4.5 W/m² in the common areas and galleries and to 18.1 W/m² in the vending area (shops, midsize stores, food store) because of the installation of LED lamps.
Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time. The concept of the zonal spatial distribution consisting of a comprehensive set of solutions that was applied that let us expect savings in energy demand of around 60% against the initial situation. These measures include:

- Daylight harvesting by 3 light tubes illuminating the centre of the sale room with natural light.
- Application of newly developed LED high lumen retail wall washer which precisely illuminates merchandise with high efficacy and homogeneity. Glare will be reduced due to very good longitudinal glare control. Beam angle was extended to 120° in order to illuminate not only the merchandise wall but also the area in front to enable optimal examination of goods by customers.
- Introduction of an evening scenario with warm-white light colour of 2700 K und reduced intensity. This lighting scene considers human biorhythm as the indoor room atmosphere is coupled with the natural outdoor lighting environment.
- Sophisticated control and monitoring strategy that enables highly differentiated space areas.

Opening hours

Starting from the strategies that BLL proposed for the City Syd democase, the schedules and the values were used as a retrofit solution for the reference building. According to BLL artificial lighting design the schedule is basically characterized by four period within a day:

- Out of Operation: is the period in which the shopping centre is closed (at night, Sunday and during holidays)
- Preparation Hours-Morning: is the period before the public opening of the shopping centre. During this time some internal activities are performed (e.g. cleaning, restock of supermarket, shops, etc…)
- Business hour corresponds to the public opening hour of the shopping centre
- Preparation Hours-Evening : same of the morning, is the period just after the closing to the public of the shopping centre



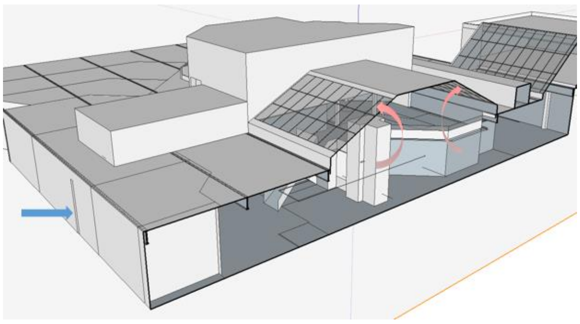
Area of application	Common areas, shops, midsize stores, service areas
Expected energy savings	63% reduction of electricity consumption due to lighting 84% cooling need reduction See appendix for detailed lighting energy analysis (CMA)
Expected impact on comfort	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping centre.
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have an impact on building energy consumption. Here, an increase in heating demand of almost 60% is expected (note the relatively low heating demand in the base case).
Expected investment costs	7.75 mil NOK

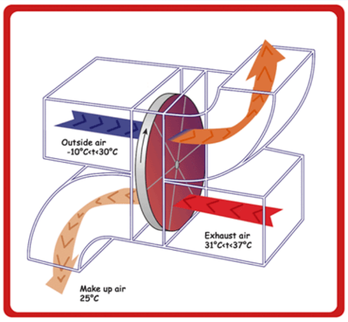
Solution 2: Appliances

Objective	To reduce energy consumption for appliances by exploiting existing systems.
Description	Appliances in shopping centres consist of • Distribution Transformers • IT Equipment (non-data centre) • Water Treatment/Distribution • PCs (Laptops, Desktops, Monitors) • Cash machines • Kitchen Equipment (in restaurants) • Refrigerators/Freezers (in supermarkets) • Video Displays/Boards • Security Systems • Vending machine • Escalators • Elevators • Security lighting The appliances will be exchanged in maintenance cycles with high efficiency products.
Area of application	Common areas, shops, offices, restaurants, warehouse
Expected energy savings	It was assumed that power consumption is appr. 985 MWh per year (10W/m^2 in the shops and 1 W/m^2 during non-operation hours) and 7W/m^2 in the CMA (during operation and non-operation hours)) and can be reduced by energy efficient appliances to 5W/m^2 (and reduced to 1W/m^2 during non-operation hours in shops and common areas). This would result in electricity savings of 389 MWh per year.
Expected impact on comfort	The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.
Interaction with other solutions	The reduced internal heat gains will reduce cooling demand and increase heating demand.
Expected investment costs	1.2 mil NOK An eco-design mechanism for shared investment of tenants should be developed.

Solution 3: Ventilation

Objective	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. Better control of ventilation (and increased airtightness) by redesign of entrance area.
Description	Natural ventilation through openable windows in the central atrium skylights help vent out stale air in the summer. Combining the effect of opened sliding doors and skylight openings can enhance stack ventilation and ventilate/cool the common areas. New entrance door to reduce infiltration.





A diagram of a rotary heat exchanger, or "heat wheel" (From Uptime Technology BV)

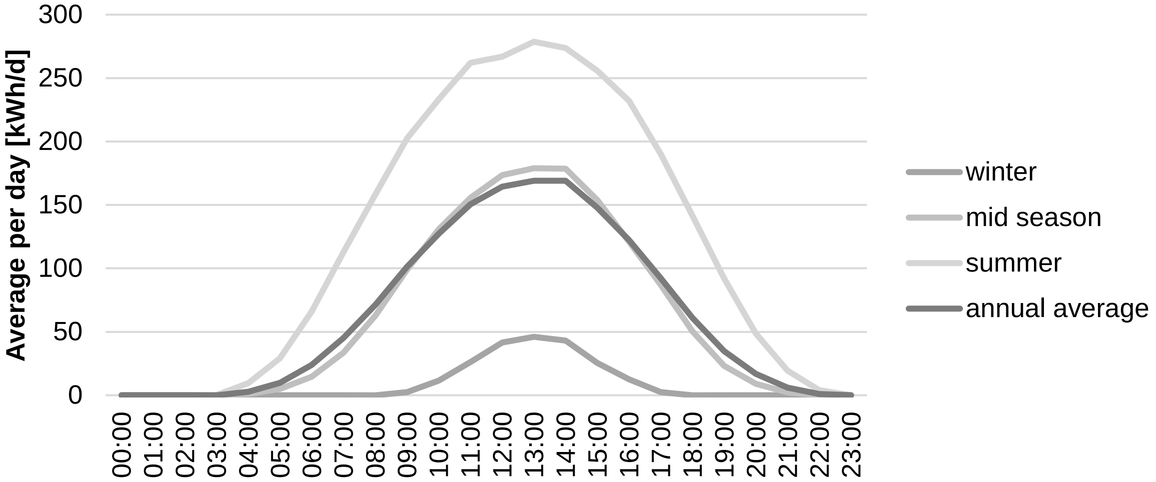
Area of application	Entrance door, atrium skylight, cooling CMA, technical rooms
Expected energy savings	30% reduction of heating need and 12% reduction of energy needs for ventilation.
Expected impact on comfort	Lower ceiling surface temperature improve thermal comfort, especially in the CMA. Improved comfort in restaurant and entrance area due to better control strategy of openings.
Interaction with other solutions	Reduction in ventilation demand of appr. 1/3.
Expected investment costs	705200 NOK

Solution 4: Heat recovery

Objective	To reduce heating demand
Description	Heating energy consumption was reduced by applying 250mm insulation on the roof, changing windows and redesign of delivery entrance area.
Area of application	Roof and delivery entrance
Expected energy savings	20% reduction in heating demand. Actual energy savings can be much higher if other solutions increase heating demand.
Expected impact on comfort	
Interaction with other solutions	Energy savings from heating demand reduction. Higher heating demand (from reduction of internal heat gains (from lighting and appliances)) will increase savings.
Expected investment costs	5.16 mil NOK

Solution 5.2: Photovoltaic plant

Objective	Peak shaving by PV + battery system
Description	6250 m² PV system (almost) horizontally installed on roof (450kWp). Battery system installed in technical room.



Area of application	Roof
Expected energy savings	Almost 560MWh electricity production which can be used to reduce electricity demand in the shopping centre. If the PV is combined with a battery energy storage system, advantageous situation are for suppling a dedicated load (e.g. lighting system) or shave the peak (only to smooth the energy profile and not strictly related to the energy prices during the day).
Expected impact on comfort	
Interaction with other solutions	Load profiles will change due to other solutions. Size of batteries (storage) depends on mismatch between (new) load and production.
Expected investment costs	12.9 mil NOK. It is expected to get incentives from enova of 3.87 mil NOK, leaving expected investment costs of 9.03 mil NOK.

Results

Energy and operative costs savings

The graph in Figure 136 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of two solution sets. Solution set 1 is based on very efficient lighting solution including light tubes (case 5) which results in very high primary energy savings from lighting. RES solution is based on 4500m² PV (750kW) saving 73 Kwh/(m² a) primary energy. In solution set 2 a lighting solution is based on the best controlled LED lighting (case 4) resulting in lower primary energy savings. RES solution is based on 6750m² PV (1MW) saving 100 Kwh/(m² a) primary energy.

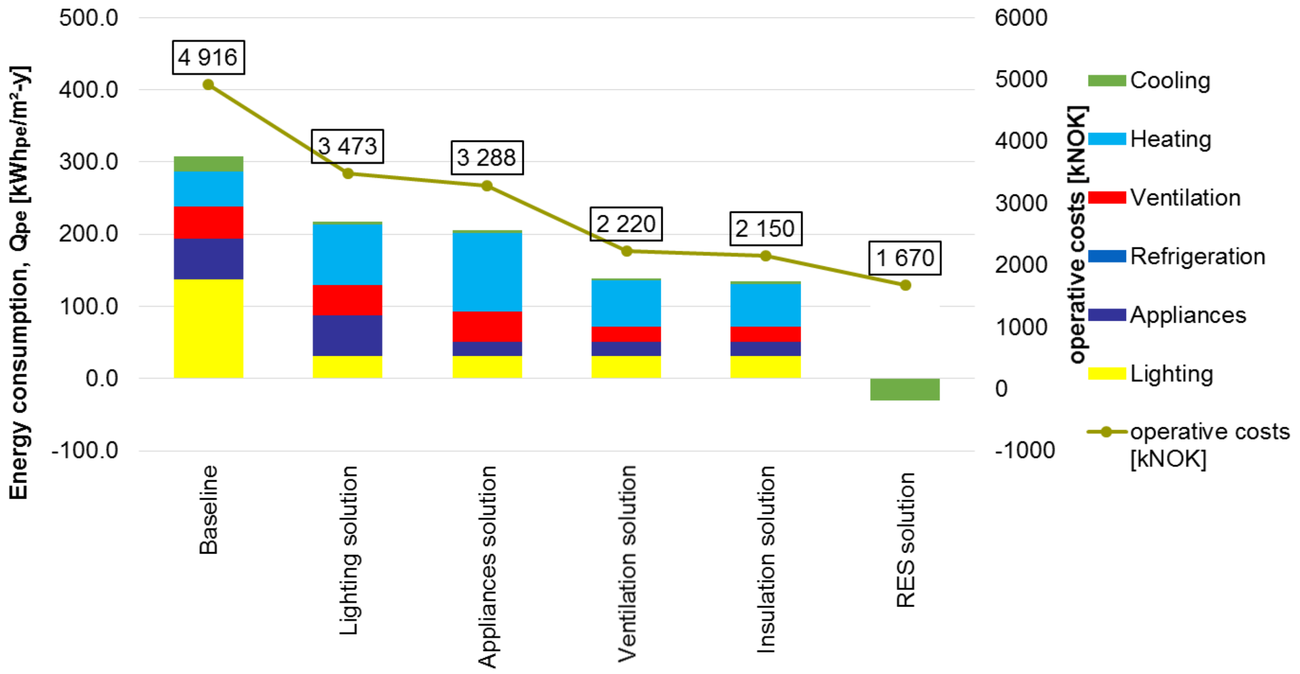


Figure 136. Yearly final energy consumption and operative costs. Solution set 1.

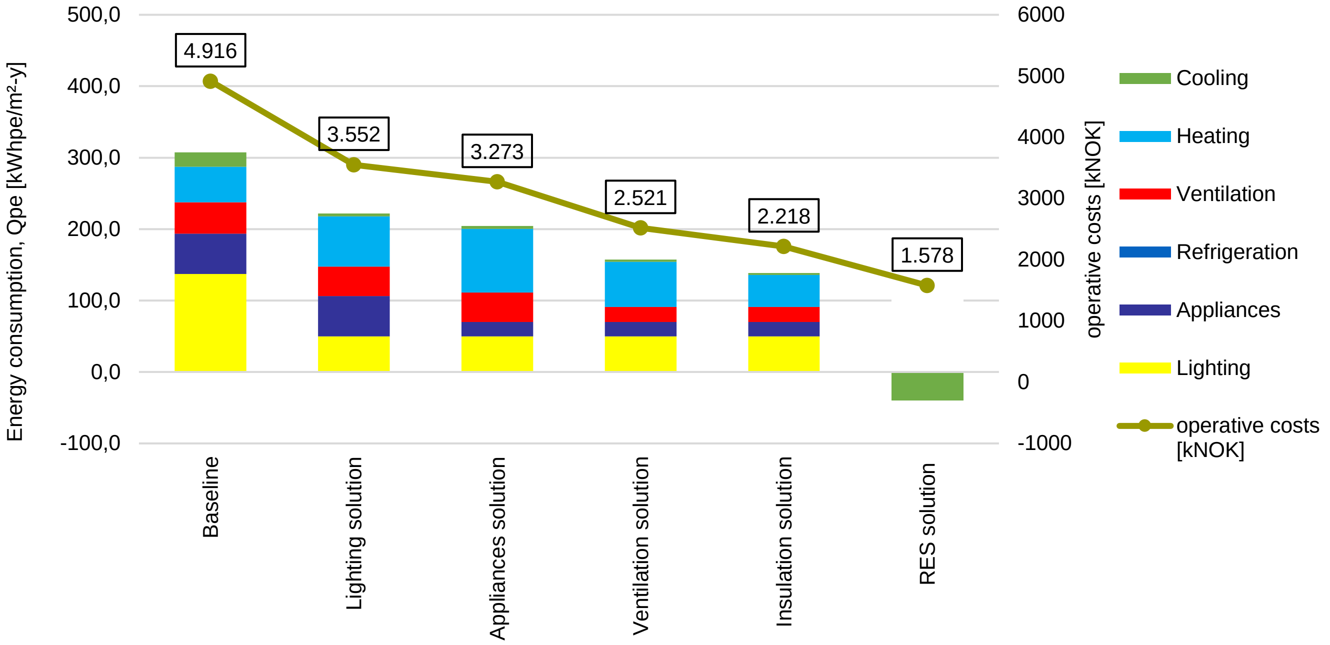


Figure 137. Yearly final energy consumption and operative costs. Solution set 2.

Primary energy savings

The graphs in Figure 138 and Figure 139 show primary energy savings of the 2 solution sets.

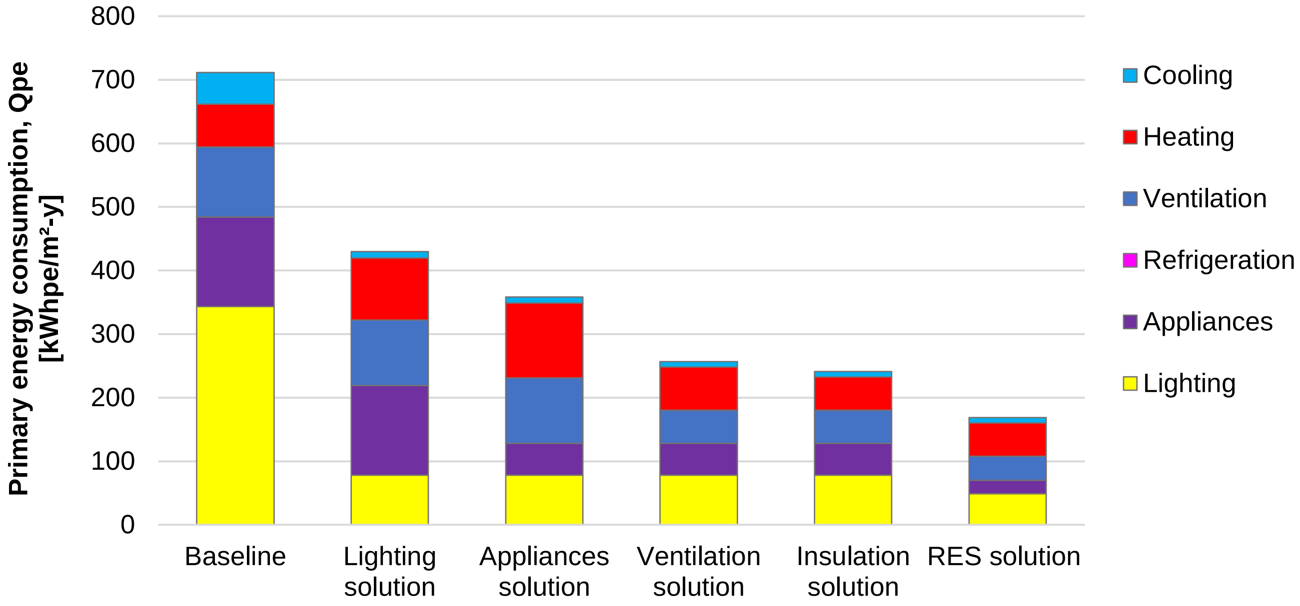


Figure 138. Primary energy savings. Solution set 1.

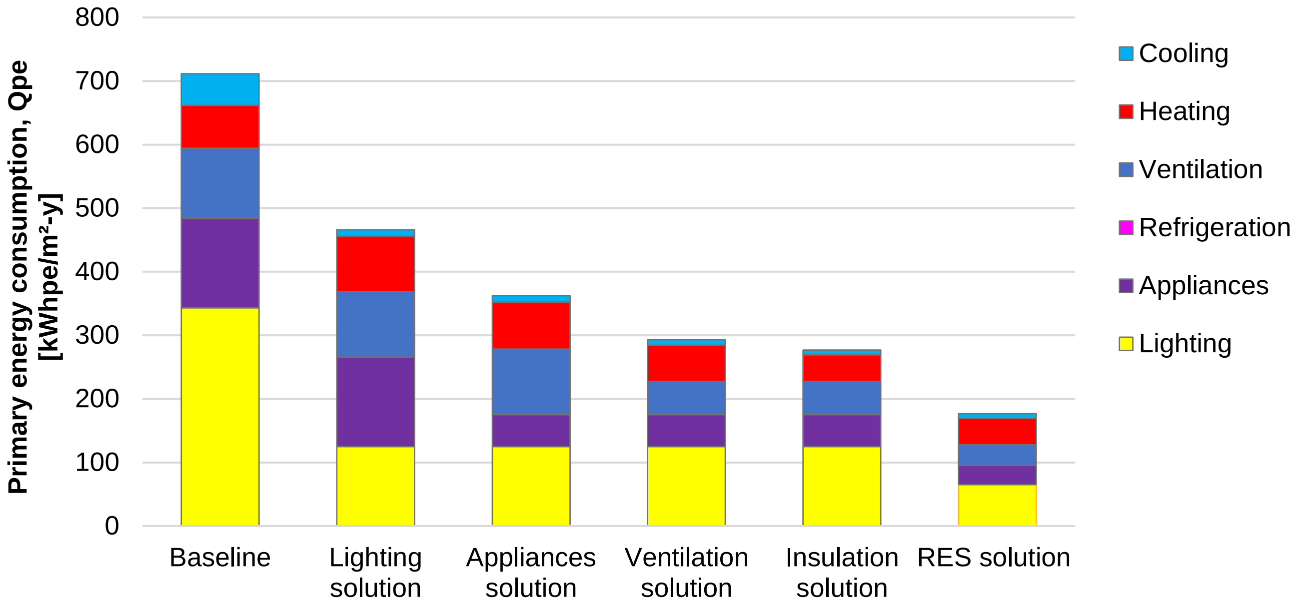


Figure 139. Primary energy savings. Solution set 2.

Economic analysis

The economic analysis is based on the assumptions listed in Table 11.

Table 11. Economic analysis assumptions.

Assumptions	Value
Year of reference (year 0)	2017
Analysis period	25 years
Discount factor	3%
Energy costs	
Cost of gas	…..
Cost of electricity	0.8 NOK/kWh
Cost of district heating	0.6 NOK/kWh
Electricity buy price annual variation	1,0%/year
Electricity sell price annual variation	1,0%/year
Installation ageing	0,5%/year
Operation costs	
Insurance	0,5%
Taxes	1,0%
Maintenance	1%
Miscellaneous supplies	0,2%
Contingency	10% from previous concepts
Annual variation	0,5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**.

For each solution set two possible scenarios are presented. First, the economic analysis resulted in a payback period of below or equal to 7 years. This means that economic constraints were identified which resulted in lower primary energy savings.

For those solution sets that resulted in the projected 75% Primary energy savings the payback periods were calculated.

The results of the cash inflows and outflows is shown over the 25 years period studied are shown in the graphs in Figure 140 to Figure 142.

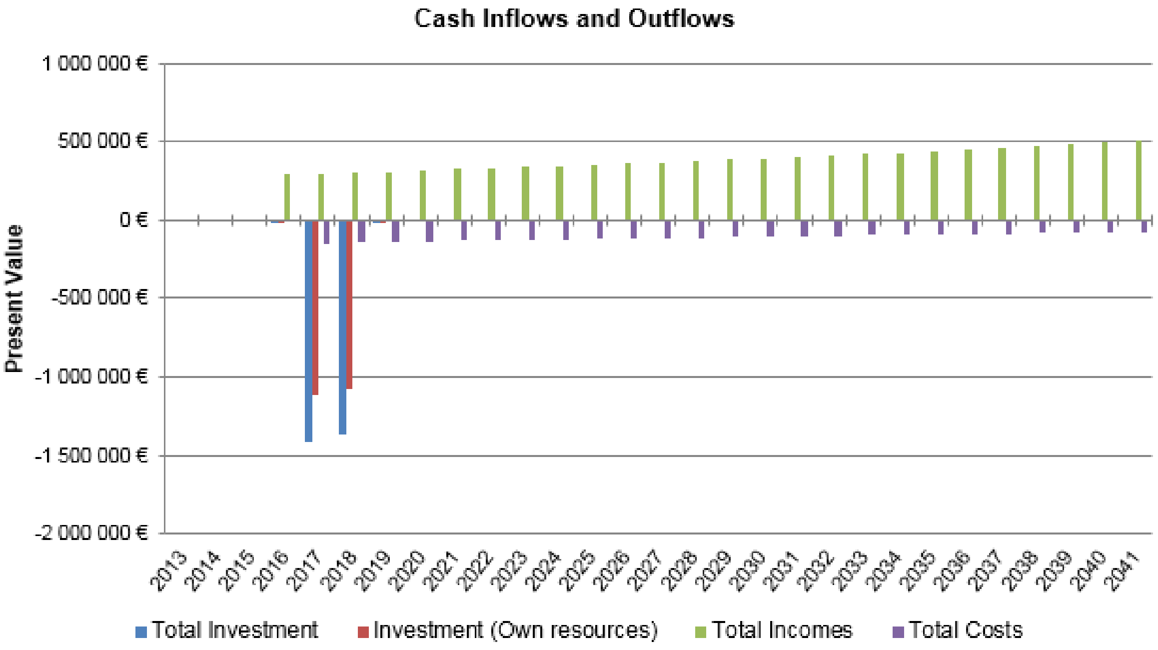


Figure 140. Cash inflows and outflows solution set 1.

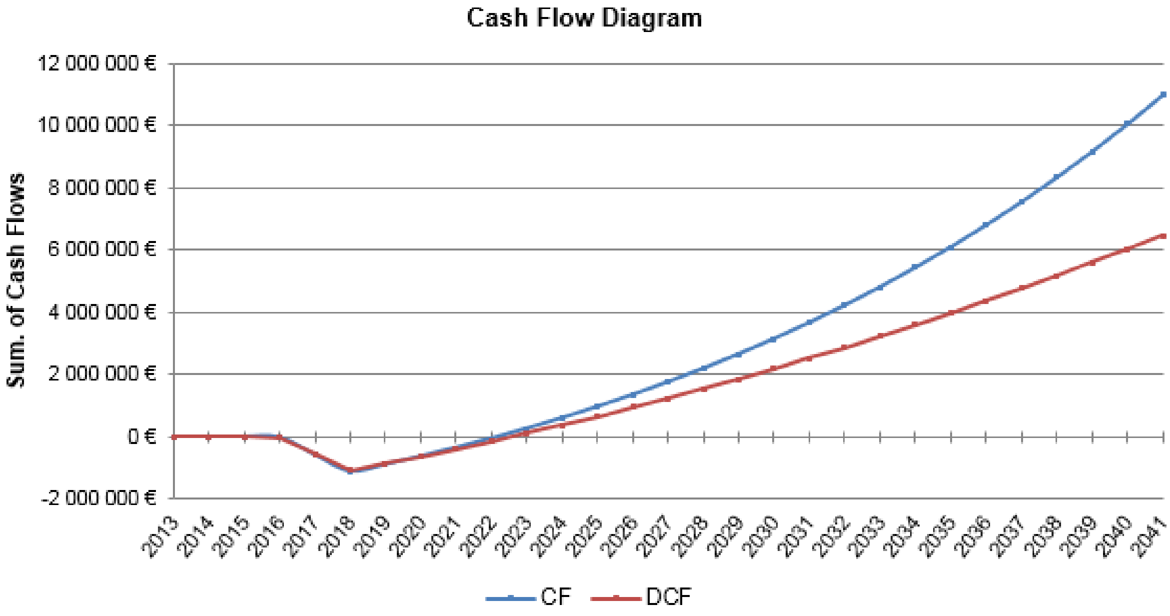


Figure 141. Cash flow diagram solution set 1.

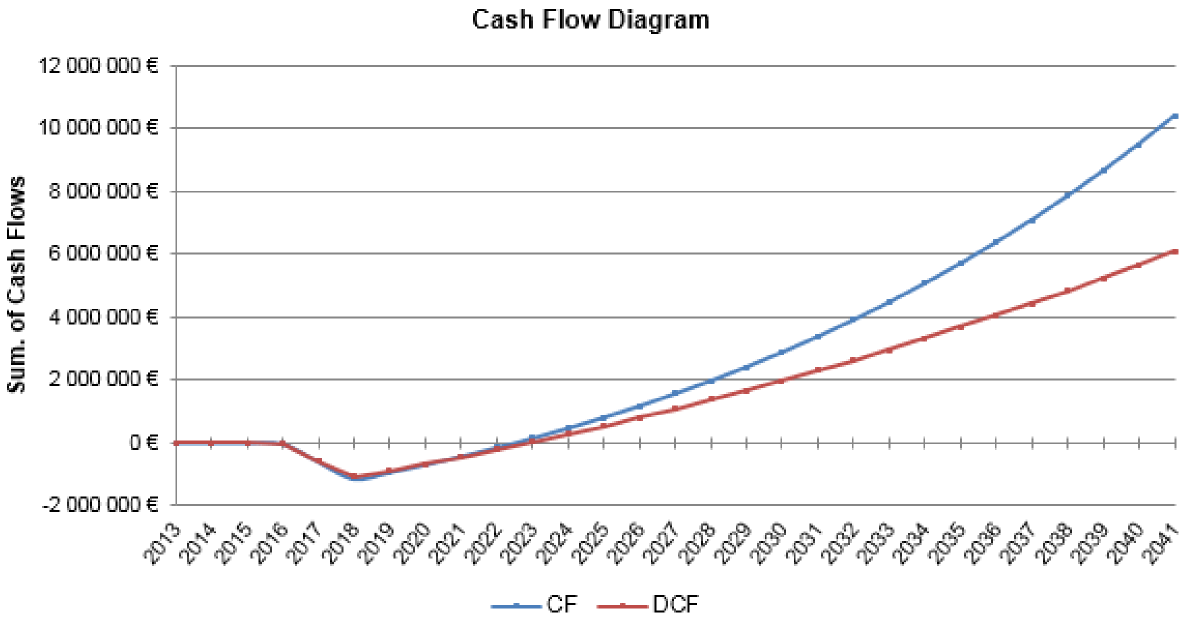


Figure 142. Cash flow diagram solution set 2.

Table 12. Economic evaluation summary

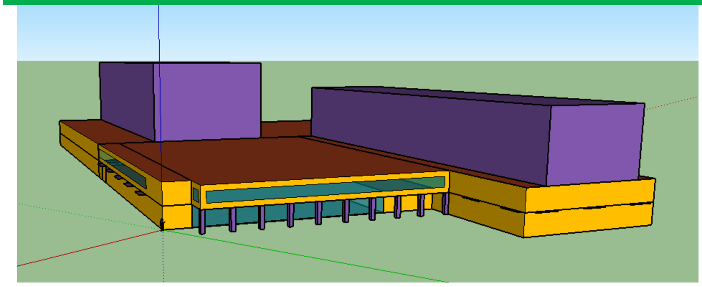
Solution-set	Individual solutions	Investment €	Operation costs savings 1st year	DPB years	PE savings %	TCOeq savings %
1a	Lighting Appliances Ventilation	1 866 962	292 970	6.57	61	63
1b	Insulation PV system	3 516 962	353 540	13.66	75	72
2a	Lighting Appliances Ventilation	1 862 702	278 507	6.92	66	63
2b	Insulation PV system	3 322 202	386 445	12.11	75	69

Coop Canaletto (Modena - Italy)

Building model: input data summary

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[5]
Common areas and galleries [m²]	521[6]
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	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/m²K]**	**g-value [-]**
Exterior window	1.4	0.622

---

[5] these zones are not included in the model
[6] these zones are not included in the model

	Food store (FDS)		**Food Production (FDP)**	
	Value	Schedule	Value	Schedule
People density [pers/m²]	0.1	07:00 – 21:00	0.08	07:00 – 21:00
Lighting density [W/m²]	40	07:00 – 21:00	45	07:00 – 21:00
Electric equipment [W/m²]	10	00:00 – 24:00	10	00:00 – 24:00
Heating setpoint temperature [°C]	20	07:00 – 20:00	20	07:00 – 20:00
Heating setback temperature [°C]	15	20:00 – 07:00	15	20:00 – 07:00
Cooling setpoint temperature [°C]	24	07:00 – 20:00	24	07:00 – 20:00
Cooling setback temperature [°C]	-	-		-
Ventilation rates [ach]	1.3	07:00 – 20:00	2	07:00 – 20:00
	0	20:00 – 07:00	0	20:00 – 07:00
Infiltration rates [ach]	0.5	00:00 – 24:00	0.5	00:00 – 24:00

HVAC systems control and efficiency

The simulation model refers only to the supermarket area. Some of the shop gallery has been retrofitted as well, but it is not directly involved in the CommONEnergy project.

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 the outside temperature goes below 4 °C, the heat pump is switched-off letting the boiler covering the entire heating demand. Otherwise, when the outdoor temperature is higher than 4°C, 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 heating demand of the market has been calculated by imposing a set point temperature of 20°C from 7 a.m. to 8 p.m. and a setback temperature of 15°C during every day. The cooling demand has been calculated by imposing a set point temperature of 24°C from 7 a.m. to 8 p.m. The cooling system is turned off during the night. No additional air humidification is considered during the winter-time.

Refrigeration system

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. Table 13 reports cabinets' characteristics.

Table 13. Characteristics of cabinets

Typology	Class	Number	Length [m]	Total Length [m]
Vertical- Closed	MT	5	3.75	18.75
Vertical- Closed	MT	2	3	6
Vertical- Closed	MT	1	1.2	1.2
Vertical- Closed	MT	1	2.5	2.5
Vertical- Closed	MT	1	1	1
ServeOver -Open	MT	2	2.5	5
ServeOver -Open	MT	2	3.5	7
ServeOver -Open	MT	1	1.2	1.2
ServeOver -Open	MT	1	1.8	1.8
Combined-Closed	LT	5	3.5	17.5
Combined-Closed	LT	1	1.8	1.8
Combined-Closed	LT	1	3.75	3.75
Vertical-1	MT	2	3	6
Vertical-1	MT	1	2.5	2.5

Simulation settings

The simulations of the baseline and the solutions that refer to the building envelope are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling set-point all the time. When studying the performance of the refrigeration cycle and the interaction between refrigeration and HVAC system, a detailed modelling of each component of the HVAC + R system has been developed. In this case, the control strategy used for the management of the whole system has a role. The simulation time step is set to 15 min for the unlimited power mode, while 5 min for the model with the HVAC+R system; a preconditioning period of a month is considered. The weather file used for the analysis is the Typical Meteorological Year (TMY), which derives from Meteonorm database (Meteotest, 2015) and is representative of the standard weather conditions in Modena.

Actual building energy consumption

Monthly electricity consumption

We compared the electricity consumption of the baseline model with the real monthly electricity consumption of the supermarket area in 2013. Figure 143 shows the comparison between the monthly electrical consumption measured and the one obtained through the baseline simulation.

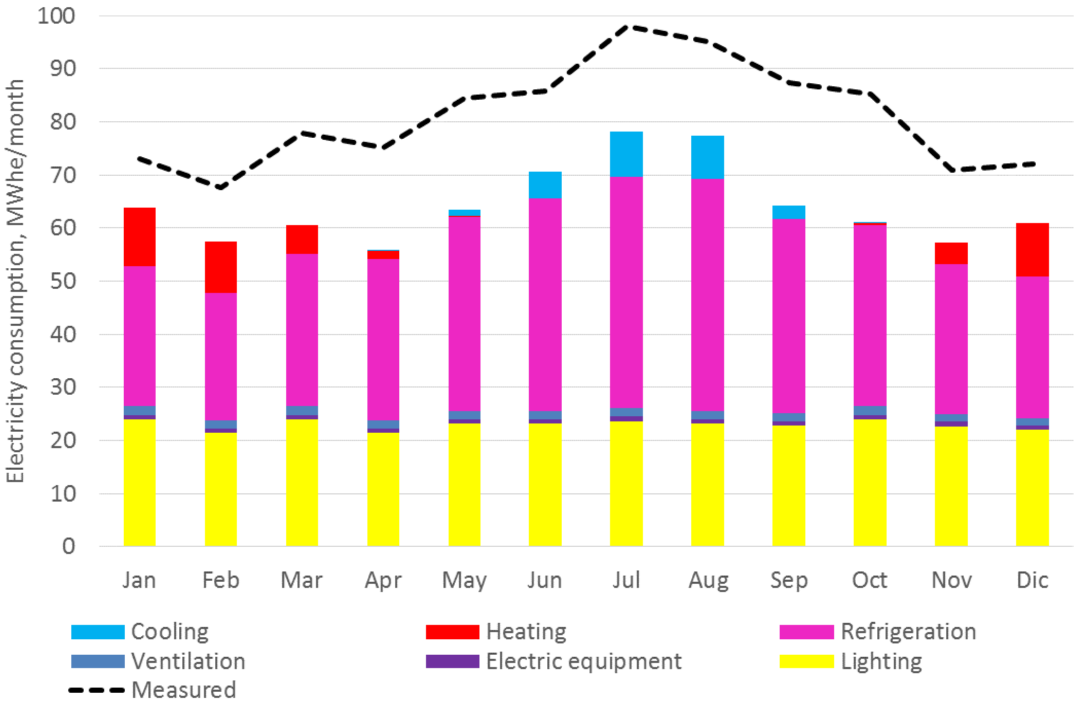


Figure 143. Monthly electrical consumption compared with the measured consumption in 2013

According to the model prediction (Figure 144), half of the electrical consumption is due to refrigeration (52%), followed by lighting (36%), HVAC (10%) and electrical equipment (1%).

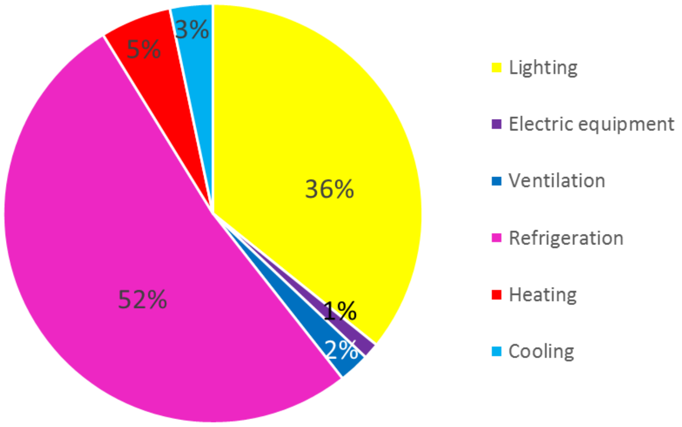


Figure 144. Predicted distribution of electrical consumption within a typical year

Daily profiles

The graphs in Figure 145 and Figure 146 represent respectively the average daily profile of electricity consumption during winter and summer. A higher electrical request on summer days is mainly due to refrigeration because of the higher outdoor temperatures and to the cooling demand of the supermarket.

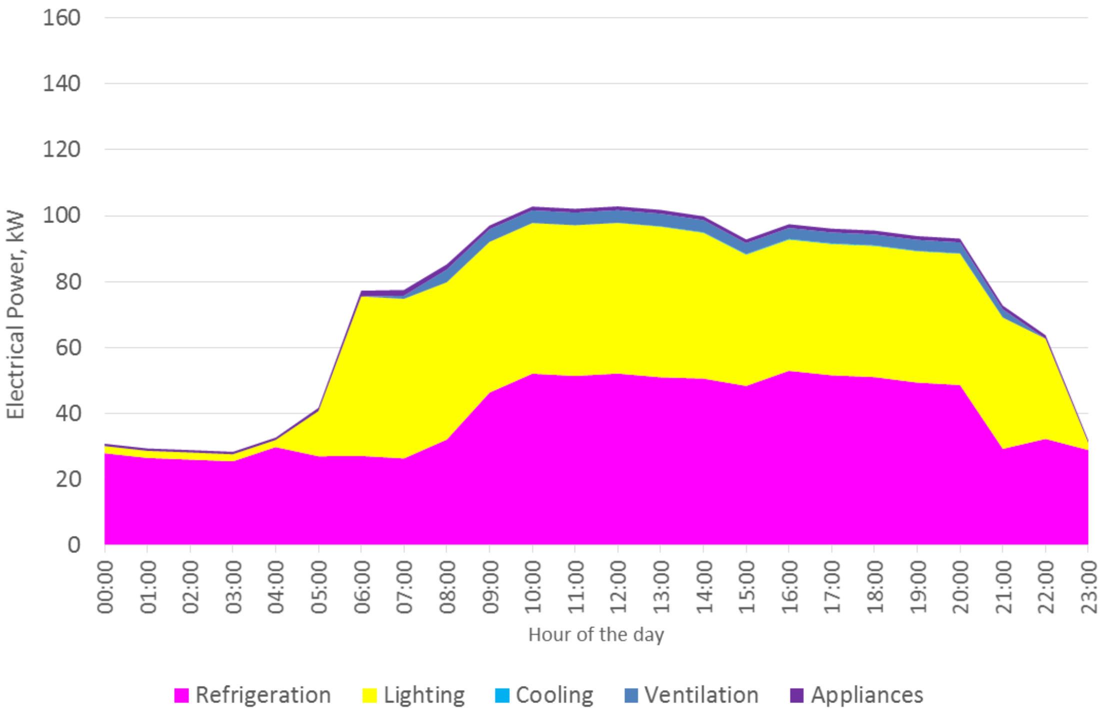


Figure 145. Daily profile of electricity consumption of the supermarket in winter from simulation results.

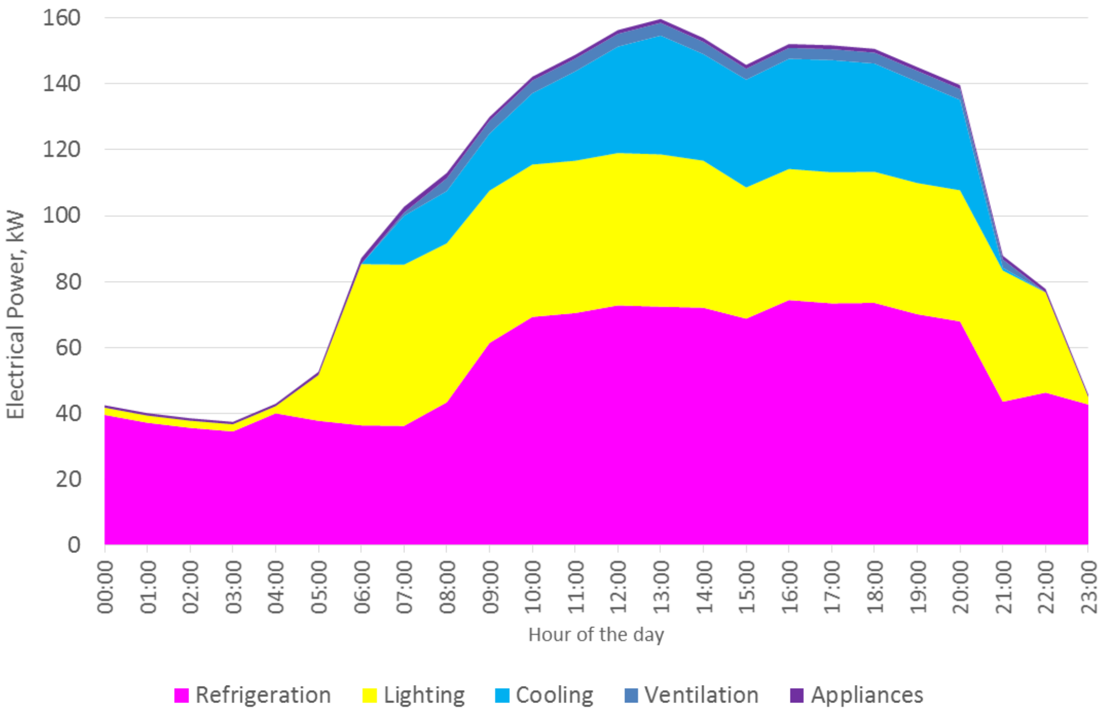


Figure 146. Daily profile of electricity consumption of the supermarket in summer from simulation results.

Total electricity consumption amounts at 781 MWh/y that corresponds to 638 kWh/m²y considering the conditioned area of 1224 m².

Solution set description

The solution set is developed to meet the specific needs of the Coop Canaletto demo case.

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. 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).

Lighting consumption affects the total electrical consumption by 36% percent and, according to literature, the lighting replacement is the most cost-effective solution for retails. For this reason, we decided first to reduce lighting power density and to dimmer during the preparation hours, i.e. before the public opening of the supermarket (**solution 1**). In this solution, we also consider the installation of twelve light tubes providing natural daylighting in the food preparation zone of the supermarket. Natural light provided by the light tubes will allow reducing the artificial lighting power needed to keep acceptable level of lighting. Because of the new internal layout of the supermarket area after refurbishment, also the food selling area will take advantages of daylighting provided by the light tubes, reducing also the lighting power need in other areas of the supermarket. With solution 1, the electricity consumption is reduced by 74%.Internal gains due to lighting reduce accordingly and affect significantly the building energy balance. Cooling need is reduced by 57%, but heating demand increases of around 22%.

Solution 2 aims at reducing electrical consumption for refrigeration, which affects half of the total electrical consumption. New terminals are installed and open cabinets are replaced with closed ones. In this way, refrigeration consumption is reduced by 57%, as well as heating demand (12%) while the cooling demand increases of one third (33%).

Solution 3 aims at reducing both heating and cooling demand, which have increased after the application of the previous solutions. This reduction is possible by improving the thermal proprieties of both opaque and new glazed facades facing both galleries and external parking area. Thanks to this solution, the heating and cooling demand are lowered respectively by 42% and 65%. This solution also affects refrigeration consumption, which is lowered by 3%.

Solution 4 consists on the application of a reflective coating (with solar reflectivity in the range of 0.7-0.9) on the roof of the gym located above the supermarket. The area interested in the application is around 800 m². With a preliminary study, thanks to the incident solar radiation analysis on the roof, we were able to select the most suitable zone of the roof for the reflective coating installation. The expected result of this solution is an energy demand reduction of around 8% with a good influence on the cooling demand reduction (around 25%) for the gym. The major effect of the coatings is to reflect solar radiation, reducing the ceiling temperature allowing for cooling reduction in summer. The application of the coating on the gym roof affects the thermal behaviour of the whole zone. Reduced surface temperatures affect transmission losses influencing also the thermal behaviour of the supermarket that is below the gym. Nevertheless, for the supermarket, simulations show that reflective coatings reduce cooling demand but also increase heating demand.

Solution 5 refers to the HVAC system. The existing (recently substituted) heat pump provides space heating and cooling; another heat pump is used for DHW preparation. The existing boiler, therefore, is dismissed with a consequent final energy reduction in the heating and cooling generation. Supply air for ventilation is pre-treated thanks to a heat recovery system installed into the AHU. An additional fan inserted in the AHU allows activating free-cooling during night and day: especially in mid-seasons and summer under determined conditions, external air is used to cool the ambient during working hours or keep lower temperatures during the night. Lower indoor temperature during the night will also affect the performance of the cabinets and the refrigeration units.

Another improvement on the HVAC system use is implemented through control strategies in order to exploit the favourable external conditions for cooling the internal ambient.

The use of the heat recovery and free cooling strategies allow respectively a 32% and 17% of final energy for heating and cooling reduction. This result is counterbalanced by a 12% increase in the ventilation consumption because fans are working also during night

Solution 6 aims at coupling HVAC and refrigeration systems to recover waste heat from refrigeration for air conditioning. A first heat exchanger transfers heat from the refrigeration cycle to the DHW preparation circuit; a second heat exchanger exploits the remaining heat in summer for post-heating and in winter for space heating, before rejecting the surplus heat through a gas cooler. In case of cooling availability from the heat pump, the waste heat is used to sub-cool the refrigeration circuit in order to increase the cycle performance. Finally, in case of cooling overproduction from the refrigeration circuit and need of cooling in the HVAC circuit, the refrigeration cycle can cover part of the cooling demand through an additional heat exchanger. Testing only the advantages of using wasted heat from the refrigeration to the HVAC system (no DHW use), the solution allows an 86% reduction of the heating consumption with just a small increase (8%) of the refrigeration consumption. Table 14 recaps the solutions proposed.

Table 14. Summary of solutions

Solutions		Description
1	**Efficient Lighting system and controls**	LED installation and new control strategy
2	**Replacement of refrigeration cabinets**	New efficient central unit and cabinets
3	**Building envelope thermal improvement**	External wall insulation and high performing glazed facade
4	**Reflective coatings**	Reflective coatings on the roof
5	**Improving HVAC efficiency**	Improvement of heating production by using heat pumps; ventilation unit with heat recovery and free-cooling mode during daytime and night time
6	**Coupling HVAC and refrigeration**	Recovery of waste heat from the refrigeration circuit for hot water production, post-heating during summer time and space heating during the winter. Use of surplus cooling load from the HVAC to sub-cool the refrigeration system; use of refrigerated water for the HVAC circuit.

Solution 1: Efficient lighting system and controls

Objective	To reduce internal gains and lighting consumption by installing more efficient lighting systems automatically controlled with respect to daylighting provided by the installation of twelve light tubes in the food store preparation zone within the supermarket
Description	Lighting power density is reduced down to 12 W/m² in the entire supermarket because of the installation of LED lamps. Advanced controls allow reducing lighting intensity by half during preparation hours, before and after the opening time. Zonal lighting concept reduces ambient lighting, accentuates zones with higher intensity and maintains the perceived brightness impression. Artificial light in food preparation area, where a defined percentage of daylight has to be provided, is controlled dependent of natural light availability with 12 light tubes. Illuminance sensors are also necessary for artificial lighting dimerization. Light tubes: view of the preparation zone and from the terrace 
Area of application	Food store selling and food store preparation
Expected energy savings	74% reduction of electricity consumption due to lighting 57% cooling need reduction 22% increase of heating need
Expected impact on comfort	Glare is reduced and Visual comfort and perception are managed to bring indoor lighting condition closer to outside natural situation (warm-white colour in the evening). Adequate illuminance level in the food preparation zone thanks to the light tubes
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need.
Expected investment costs	For the economic analysis we use real cost data: Efficient and dimmer lamps (LED technology) 47.8 €/m² (1224 m²) Light tube 2086 €/each (nr 12) Illuminance sensors 78 €/sensor (nr 5) The costs include the installation costs but not taxes

Solution 2: Replacement of refrigeration cabinets

Objective	To reduce refrigeration consumption
Description	The solution consists in reducing the refrigeration consumption by replacing old low efficient cabinets with closed new ones (76 m of cabinets) which have better performance and reduced energy consumption
Area of application	Food store selling area
	
Expected energy savings	57% reduction of refrigeration consumption 12% reduction in heating demand 33% increase of cooling demand
Expected impact on comfort	More uniform temperature distribution between cabinets corridors and the rest of the supermarket
Interaction with other solutions	Efficient cabinets will affect both heating and cooling demands. While heating demand is decreased, the cooling demand is increased (around 33% more) because of the reduction of cooling gains due to the open cabinets.
Expected investment costs	The cost of investment for the cabinets replacement is 2400 €/m (installation incl., taxes excl.)

Solution 3: Building envelope thermal improvement

Objective	To reduce energy consumption for heating and cooling
Description	External walls are insulated with 7 cm of PIR insulation (applied on the interior side). Total U-value of the wall is 0.26 W/m^2 K; 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 Ug = 1.01 W/m^2K , g-value= 0.28 and aluminium frame with Uf= 0.9 W/m^2K
Area of application	Insulation of around 250 m^2 of wall 235 m^2 of new glazed facade

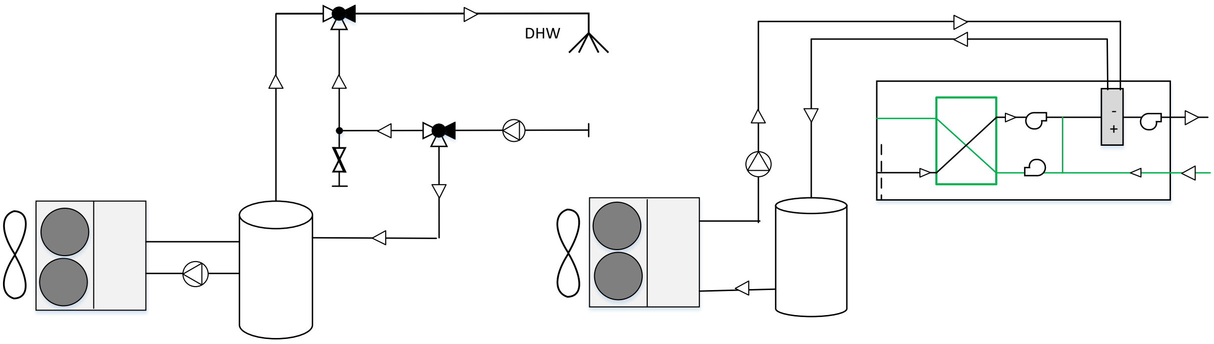
Expected energy savings	42% of heating demand reduction 65% of cooling demand reduction 3% increase on the refrigeration consumption
Expected impact on comfort	Performant glazed façade allow to restrained discomfort condition close to the perimetral area of the supermarket because of the solar gain coming from outside, especially during summer period.
Interaction with other solutions	A better performing envelope improve the energy balance of the building allowing for a decrease of both heating and cooling demand.
Expected investment costs	For the economic analysis we consider the real cost of intervention which are : • 9000 € (36 €/m^2 material + installation, taxes excl.) for the thermal insulation of the opaque surfaces (around 250 m^2) • 64,155 € (273 €/m^2 material + installation, taxes excl.) for the new glazed façade (around 235 m^2)

Solution 4: Reflective coatings on the roof

Objective	To reduce energy need by applying reflective coatings on the roof
Description	Application of reflective coatings (70-90% reflectivity) on the gym roof area, The coating has also anti-bacteria, anti-mold and self-cleaning properties.
Area of application	The application area is around 800 m² and it has been identified as the most suitable zone for the coating application since it is not affected by the shading produced by closer tall buildings (e.g. apartment stock) 
Expected energy savings	Energy saving on cooling demand (3%)
Expected impact on comfort	Indoor surface roof temperature will be lower or higher depending on the season resulting in a more uniform temperature inside the gym improving costumers thermal sensation
Interaction with other solutions	The application of the reflective coating has impact on the energy demand of the supermarket because of the thermal losses reduction.
Expected investment costs	As initial investment cost we considered 9600 € (12 €/m² over a surface of 800 m², installation incl., taxes excl.)

Solution 5: Improvement in HVAC efficiency

Objective	Reduction of energy consumption for the air conditioning acting on the generation side and pre-treatment of supply air. Exploitation of mechanical free cooling during daytime and nigh-time
Description	Replacement of the existing generation system (boiler + heat pump) with the heat pump only for the heating and cooling production. DHW preparation is provided by an additional heat pump. Installation of a heat recovery section (heat exchanger plus supply and exhaust fan), in the original Air Handling Unit to pre-treat the supplied air. Mechanical free-cooling during daytime and night-time to reduce cooling consumption.



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.

Area of application	Supermarket area
Expected energy savings	32% of heating consumption reduction 17% of cooling consumption reduction 12% increase in the ventilation consumption because of the additional fan for the free-cooling and the working during night.
Expected impact on comfort	The free cooling exploitation will allow a reduction of the peak temperature during the day especially during mid-seasons; lower temperature during the first opening hours.
Interaction with other solutions	The indoor thermal condition coming from the exploitation of free cooling strategies can affect the performance of the refrigeration system.
Expected investment costs	The investment cost is related to the installation of the heat recovery unit which cost is around 5280 € (installation incl., taxes excl.).

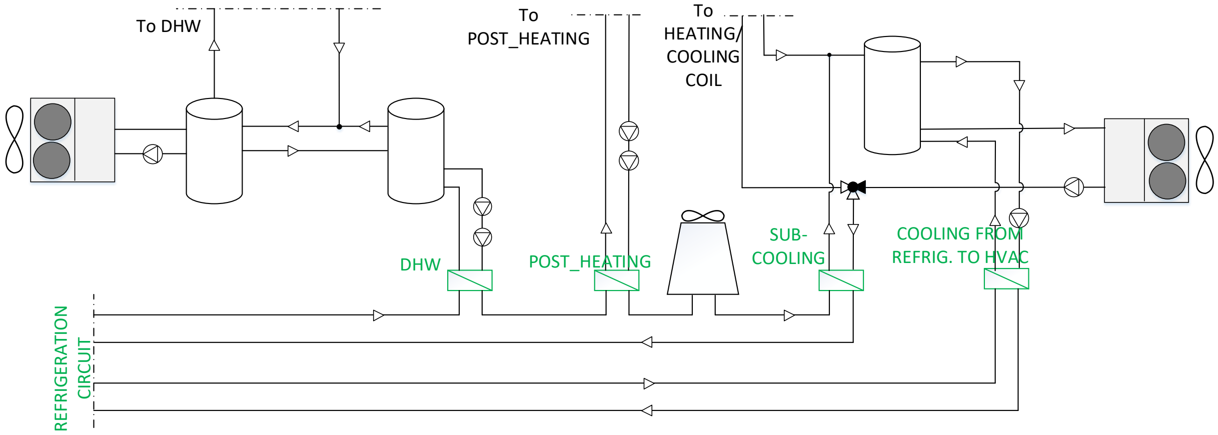
Solution 6: New CO_2 transcritical refrigeration system coupled with HVAC

Objective

To couple refrigeration and HVAC system; improving the overall system performance.

Description

The central refrigeration unit is replaced with a new one using CO_2 as refrigerated fluid. The performance is comparable to the traditional ones while the environmental impact is highly reduced. The solution aims to integrate refrigeration and HVAC systems. 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.
In this solution we test the use of rejected heat from the refrigerated circuit to the space heating controlling the return water temperature at 35 ºC.



Area of application

Supermarket area

Expected energy savings

Energy savings are expected in the DHW production, as there is continuously an available heat source and also on the heating used by the AHU. Moreover, the decrease of the refrigerant fluid temperature through sub-cooling increases the refrigeration circuit efficiency and, consequently reduces the electricity consumption. Considering only the exchange between the refrigeration circuit and the AHU, the expected savings are:
86% reduction of the heating consumption
6% increase in the fan consumption
8% increase of the refrigeration consumption

Expected impact on comfort

No specific impact on the comfort is expected as there is a back-up system (heat pump) for heating and cooling.

Interaction with other solutions

In this solution, the refrigeration system interacts with the HVAC system: waste heat from the refrigeration system is used for DHW preparation and space heating; cooling from the heat pump is used to sub-cool the refrigeration cycle; cooling from the refrigeration system is used to integrate the cooling production of the HVAC system.

Expected investment costs

As investment cost we consider 61000 € extra cost needed for implementing the technological solution of CO2 coupled with HVAC (CO_2 transcritical refrigeration plant and heat exchangers needed for the systems coupling) compared to a standard refrigeration solution.

Results

In this section the results coming from the simulations are presented and discussed.

Energy and operative costs savings

The graph in Figure 147 shows the actual yearly final energy consumption of the baseline model and the potential energy savings obtained implementing the retrofit measures described in the previous section. The graph in Figure 148 shows the potential primary energy reduction. The solution set package analysed leads to a reduction of 62% of electricity/primary energy consumption.

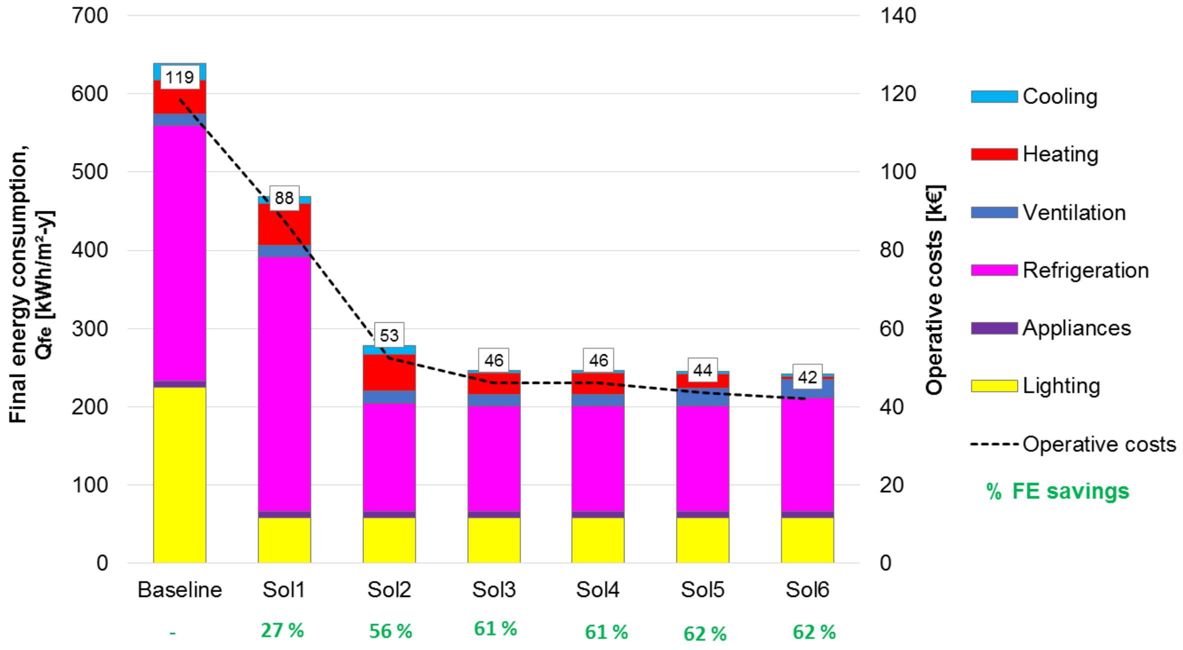


Figure 147. Yearly final energy consumption and operative costs in Coop Canaletto supermarket

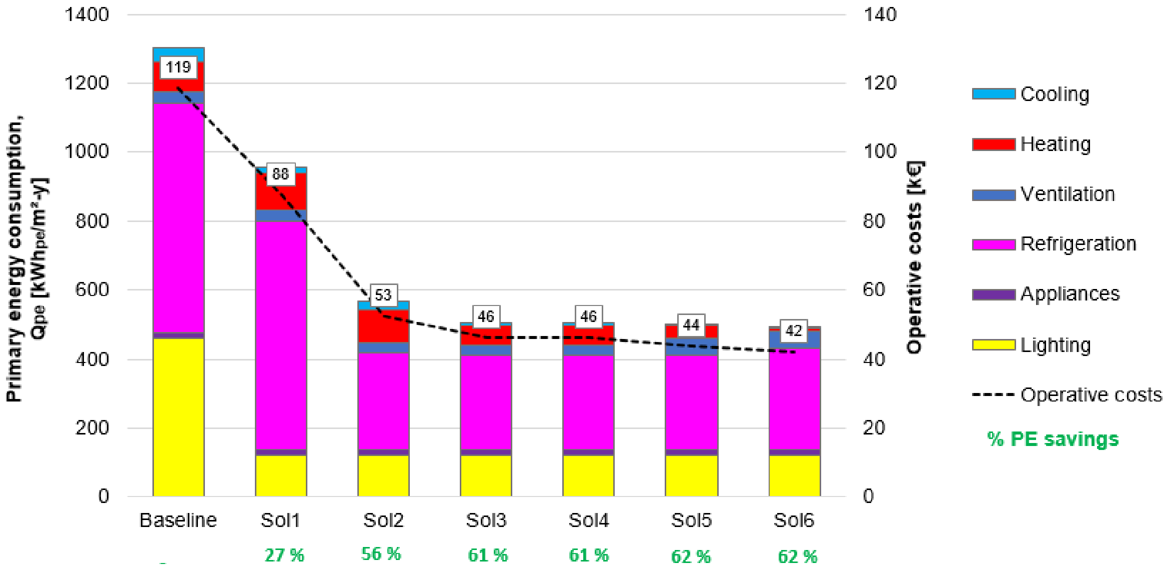


Figure 148. Yearly primary energy consumption and operative costs in Coop Canaletto supermarket

Economic analysis

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 607’000 €, most of which is due to the refrigeration plant.

Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 501,000 €/year.

Table 15. Assumptions on cost of investment of the solution sets

Equipment	Cost
Efficient and dimmer lamps	40,950 €
Light tubes	20,024 €
Illuminance sensors	312 €
Refrigeration	152,000 €
Insulation opaque façade	7,201 €
Performant glazed façade	51,324 €
Reflective coating	7,680 €
Hear Recovery section for AHU	4400 €
Extra cost for transcritical CO2 refrigeration system + heat exchanger for coupling HVAC and refrigeration system	61000 €
Installation cost (20% of equipment costs)	82,585.0 €
Engineering and Permitting (10% of equipment costs)	34,457.9 €
Total	**461,933.5 €**
Tax (31.4%)	145,047.12 €
Total cost of investment (incl. tax)	**606,980.6 €**

The economic analysis is based on the assumptions reported in Table 16.

Table 16. Economic analysis assumptions

Assumptions	Value
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	0 - 8 %
Energy costs	
Cost of gas	0.0748 €/kWh
Cost of electricity(buy)	0.15 €/kWh
Electricity buy price annual variation	1.0%/year
Electricity sell price annual variation	1.0%/year
Installation ageing	0.5%/year
Operation costs	
Insurance	0.5%
Taxes	0%

Maintenance	3%
Miscellaneous supplies	0,2%
Contingency	10% from previous concepts
Annual variation	0.5% each

For the viability study of each scenario, the **Discounted Cash Flow (DCF)** has been used. DCF is a cash flow summary adjusted so as to reflect the **time value of money**. The result of the cash inflows and outflows is shown over a 25 years period.

Table 17 reports partial results of the economic analysis performed by progressively stacking energy conservation and energy efficiency measure.

The results of the cash inflows and outflows for the whole solution set over the 25 years period studied are shown in the graphs in Figure 149 and Figure 150.

The estimated Pay Back Time is expected to be between **7.3 (discount factor 0%) and 11 years (discount factor 8%)** depending on the discount factor which can be applied to the investment.

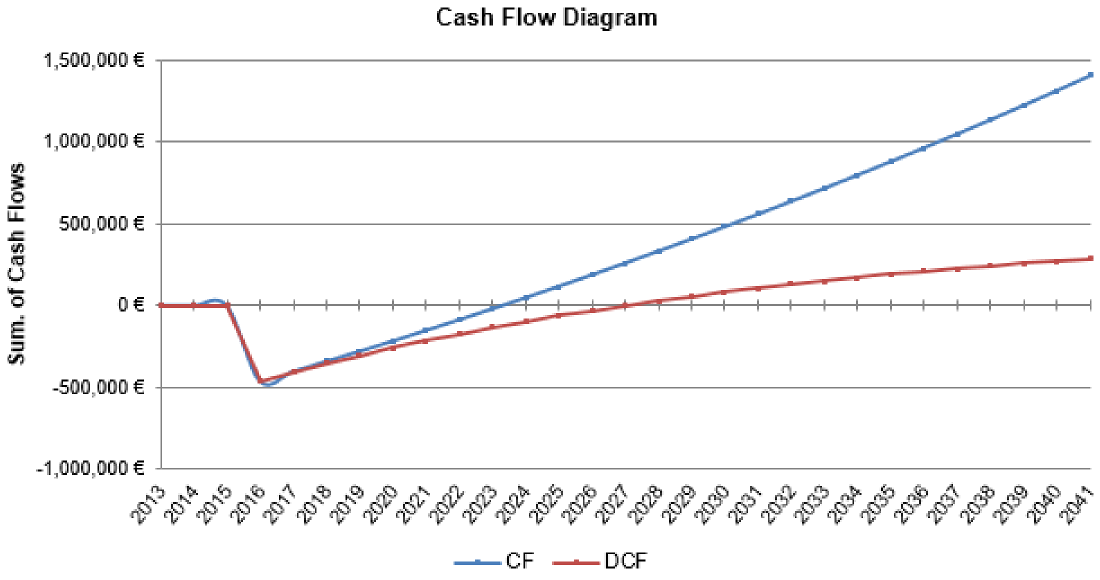


Figure 149. Cash flow diagram for the solution set when discount factor is equal to 8%

Table 17. Economic analysis on stacked measures

Solution		Investment individual solution [€]	Total investment [€]	Operation cost savings [€/year]	Energy savings [kWh/year]	Energy savings [%]	ROI [%]	Pay Back Time [years]	Net Present Value [€]	Discounted Pay Back Time [years]	Discounted Net Present Value [€]
1	Efficient lighting system and control	118,282.9 €	118,282.9 €	30,906 €	208,234	27	31.4	3.2	648,091.1 €	3.9	219,268.4 €
+2	Improvement in refrigeration efficiency	259,646 €	377,929.3 €	65,971 €	440,871	56	19.6	5.1	1,193,993.7 €	6.8	333,179.7 €
+3	Building envelope thermal improvements	103,816.7 €	481,745.9 €	72,358 €	479,333	61	16.2	6.1	1,207,369.0 €	8.7	292,860.3 €
+4	Reflective coating	13,623.6 €	495,369.5 €	72,365 €	479,403	61	15.6	6.3	1,186,860.6 €	9.1	278,239.4 €
+5	Improvement in HVAC efficiency	7,516.1 €	502,885.6 €	74,886 €	490,449	62	16.1	6.2	1,243,027.5 €	8.8	298,452.2 €
+6	Coupling HVAC and refrigeration	104,095.6 €	606,980.6 €	76,518 €	501,327	62	14	7.3	1,402,267.7 €	11	282,364.6 €

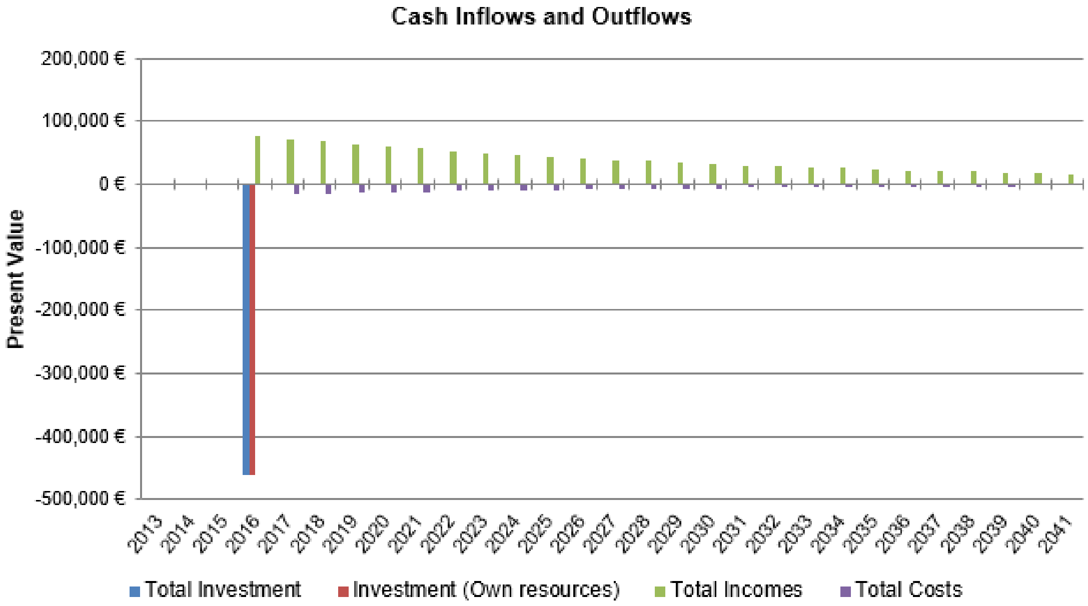


Figure 150. Cash Inflow and outflow for the solution set when discount factor is equal to 8%

Conclusions

The document presents the solution set implemented in the Coop Canaletto supermarket within the demonstration activities of CommONEnergy. The solution set reflects the specific needs of Coop Canaletto demo case, a small size supermarket which is planned to be completely restyled.
The solution-set proposed includes:

- Solution 1: Efficient lighting system and controls
- Solution 2: Replacement of refrigeration cabinets
- Solution 3: Building envelope thermal improvement
- Solution 4: Reflective coatings
- Solution 5: Improving HVAC efficiency
- Solution 6: Coupling of HVAC and refrigeration system

The Integrated Modelling Environment developed within the CommONEnergy project allowed us to take into account the interaction between solutions and to assess the overall energy savings of the solution set package and of each solution stacked on the previous applied ones.
The results highlighted how improvements in the refrigeration efficiency both from generation side (CO_2 transcritical system) and terminal units (closed cabinets) are essential measures for upgrading the overall energy efficiency of the supermarket opening the possibility of an HVAC – refrigeration coupling. Despite the significant investment costs of around **606,980 €** (incl. tax), the solution set is cost-effective.
The proposed solution set package in fact, can lead to an overall reduction of **62%** of electricity consumption. Considering an average cost of electricity of **0.15 €/kWh**, the energy savings due to energy

conservation and efficiency measures from solution 1 up to solution 6 are expected to be **76,518 €** in the first year of operation after retrofit.

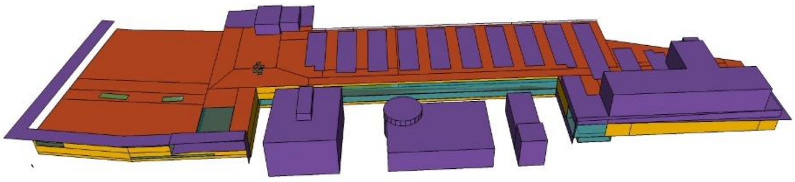
The estimated Pay Back Time of the solution set is expected to be between **7.3 (discount factor 0%) and 11 years (discount factor 8%)** depending on the discount factor which can be applied to the investment**.**

Coop Valbisagno (Genoa - Italy)

Building model: input data summary

General data	
Gross floor area [m²]	21245
Gross Leasable Area [m²]	24349
Food store vending area [m²]	6352
Tenants vending area [m²]	10708
Common areas and galleries [m²]	3667
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]	4.5

Thermal zone model



Number of thermal zones	37
First floor height [m]	5.00
Second floor height [m]	7.40
Zone typology	**Zone group area [m²]**
Shops	4074
Medium size store	6634
Food store	6352
Warehouse	1188
Restaurant	985

Building envelope

Opaque envelope components	U-value [W/m²K]	Solar absorptance [-]
Exterior walls	0.367	0.6
Adjacent walls	0.779	0.6
Exterior roof	0.207	0.6
Ceiling/interior floors	0.353	0.6
Ground floor	0.364	0.6
Glazed envelope components	**Ug [W/m²K]**	**g-value [-]**
Exterior window	1.4-1.8	0.8

	Common areas		**Shops**		**Medium size stores**		**Food store**		**Warehouse**		**Restaurant**	
	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule
People density [pers/m²]	0.20	08:00 – 20:00	0.2	08:00 – 20:00	0.25	08:00 – 20:00	0.25	08:00 – 220:00	0.1	06:00 – 19:00	0.25	08:00 – 23:00
Lighting density [W/m²]	8.0	06:00 – 21.00	30.0	06:00 – 21.00	27.0	06:00 – 21.00	30.0	06:00 – 21.00	15.0	08:00 – 20.00	28.2	08:00 – 22.00
Electric equipment [W/m²]	10	06:00 – 21.00	10	06:00 – 21.00	10	06:00 – 21.00	5	06:00 – 21.00	10	07:00 – 18.00	10.0	07:00 – 23.00
Heating setpoint temperature [°C]	20	07:00 – 19:30	20	07:00 – 19:30	20	07:00 – 19:30	20	07:00 – 19:30	18	07:00 – 18:30	20	08:00 – 23:00
Heating setback temperature [°C]	15	19:30 – 07:00	15	19:30 – 07:00	15	19:30 – 07:00	15	19:30 – 07:00	15	18:30 – 07:00	15	23:00 – 08:00
Cooling setpoint temperature [°C]	25	07:00 – 19:30	25	07:00 – 19:30	25	07:00 – 19:30	25	07:00 – 19:30	25	07:00 – 18:30	25	08:00 – 23:00
Cooling setback temperature [°C]	30	19:30 – 07:00	30	19:30 – 07:00	30	19:30 – 07:00	30	19:30 – 07:00	30	18:30 – 07:00	30	23:00 – 08:00
Ventilation rates [ach]	2.0	08:00 – 20:00	2.0	08:00 – 20:00	2.0	08:00 – 20:00	2.0	08:00 – 20:00	0.5	08:00 – 20:00	4.0	08:00 – 23:00
Infiltration rates [ach]	2.0	00:00 – 24:00	2.0	00:00 – 24:00	2.0	00:00 – 24:00	2.0	00:00 – 24:00	2.0	00:00 – 24:00	2.0	00:00 – 24:00

HVAC systems control and efficiency

Due to the complexity of the building and the number of circuits, we have modelled and simulated the HVAC systems for the food-store, common areas and mid-stores only. In these zones, the HVAC system has been modelled with all its components. The other zones have been kept with the ideal loads calculation that uses unlimited power, able to guarantee the indoor temperature within heating and cooling set-point all the time.

Despite the original plan of having rooftop machines, the reported results refer to a system with water-to-water heat pumps as it has been studied the water loop solution. In light of this, the implemented system foresees three water-to-water heat pumps, one for each zone typology (food-store, common areas, mid-stores) connected in a water-loop. The water temperature in the loop is maintained between a certain range (10-25°C) by a dry cooler working in winter and summer mode.

Each zone typology is conditioned by an AHU fed by one of the three heat pumps. The AHU is composed by a heat recovery, cooling and heating coils and recirculation valve. Then the conditioned air is split into each thermal zone.

The units recover part of the exhaust air and mix it with outdoor air: the portion of recirculated air is regulated for guaranteeing the minimum air changes rate. Full recirculation mode is set in the first opening hours until the set-point indoor temperature is reached. The system works at minimum air changes rate when free-cooling is activated and with increased air flow when it is conditioning.

From the simulation with unlimited power of the model, the total capacity of the heat pumps have been defined as reported in Table 18. In the numerical model, each heat pump is composed by more than one compressor in order to allow working with partial loads.

Table 18. Calculated capacity for the heat pumps divided per zone typology

	Heating capacity [kW]	Cooling capacity [kW]
Foodstore	1120.5	682.1
Mid stores	806.4	832.6
Common Areas	637.2	450.3

Based on the thermal zones loads, the ventilation rates of the single AHU have been defined as shown in Table 19.

Table 19. Features of the Air Handling Units (AHU) that condition the shops.

ID	Description	Supply flow rate [m³/hr]	Supply - Pressure drop [Pa]	Extract flow rate [m³/hr]	Extract - Pressure drop [Pa]
AHU_FDS	Food store	190000	950	160000	750
AHU_MDS	Mid-stores	140000	850	119000	600
AHU_CMA	Common Areas	110000	800	90500	500

For the shops' air conditioning, we considered the following efficiencies to estimate the electricity consumption:

- EER = 3

- COP = 3.5

The 70% of the maximum damper opening is set as the minimum hygienic air changes. The ventilation flow rate is calculated in order to be able to cover the maximum building load.

During the non-occupied time the fan is switched off. Pumps, fans and heat pumps are modelled based on generic components' datasheet as the specific models were not available.

Refrigeration

Refrigerated cabinets and cold rooms' typologies and quantities are based on the designed ones. Table 20 and Table 21 list the characteristics of the refrigerating devices.

The refrigeration is based on a cascade system with CO_2 as refrigerant for the direct expansion LT (Low Temperature) equipment, and R134a as refrigerant for the MT (Medium Temperature) portion of the system.

Table 20. Refrigerated cabinets in the food store.

ID	Tot length [m]	Temperature class	Typology	Open/closed	Rated cooling capacity [W/m]
LT1	49.4	L1	horizontal	closed	208
LT2	15.6	L2	combined	closed	553
MT1	7.5	H1	semi-vertical	open	1548
MT2	43.3	M^2	horizontal	closed	558
MT3	11.25	M1	vertical	closed	650
MT4	16.85	M^2	horizontal	open	620
MT5	49.65	H1	vertical	open	216
MT6	9.4	M^2	serve over	open	274
MT7	15	H1	semi-vertical	open	1016

Table 21. Cold rooms in the food department.

	Floor area [m^2]	Rated cooling capacity [W]
CR1	19	2892
CR2	11.33	1724
CR3	3.45	525
CR4	11.67	1776
CR5	9.33	1775
CR6	13	1979
CR7	6	913
CR8	2.46	374
CR9	2.46	374
CR10	14.33	2726
CR11	7.31	1239
CR12	5.2	881

Simulation settings

Simulations are performed modelling all the parts of the system: building, HVAC system, refrigeration system, lighting, storages, PV system. For the sake of simplicity, the loads of some zones of the mall are

calculated with unlimited power, able to guarantee the indoor temperature within heating and cooling set-point all the time. The time step is set to 5 min and a preconditioning period of a month is considered.
The weather file used for the analysis refers to the Typical Meteorological Year (TMY) derived from Meteonorm database (Meteotest, 2015) and is supposed to be representative of the standard weather conditions.

Actual building energy consumption

This section is not valid in this case as the reference/existing building has different shape and building uses than the renovated one.
Numerical models have been calibrated on the basis of components datasheets or with comparison with similar malls/climates. Simulation results will be adjusted once monitored data will be available.

Daily electricity profiles

The heating demand of the shopping mall is calculated assuming a set point temperature of 20°C from 8am to 8 pm during every day in shops, common areas, food store, medium size stores and service zones. A heating set point temperature of 18°C is set in the warehouse zones. The cooling demand is calculated assuming a set point temperature of 25°C from 8 am to 8 pm during every day in shops, common areas, food store and medium size stores.
No additional air humidification is considered during the winter time, whereas no attenuation during the night-time is applied.

Electricity consumption

The graph in Figure 151 represents the electricity consumption divided by zone function. The mid-size stores (MDS) have the highest electricity consumption due to the high lighting power density and, consequently, high cooling demands. According to our model predictions, the most affecting energy use is due to lighting (51%) followed by other electric equipment (16%), ventilation (12%), refrigeration (7%), cooling (9%) and heating (4%).

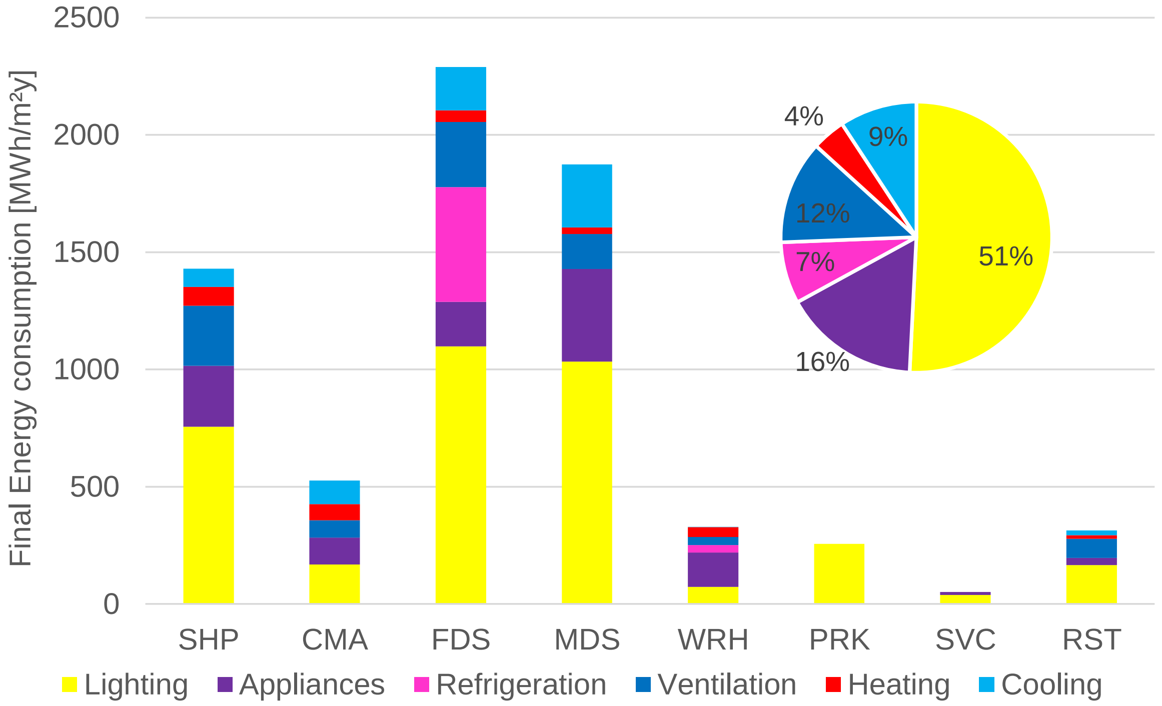


Figure 151. Electricity consumption for each group of zones: Common Areas (CMA), Shops (SHP), Midsize store (MDS), Food store (FDS), Offices (OFF), Warehouse (WRH)

Total electricity consumption amounts at around 7070 MWh/y which corresponds to 290 kWh/m²-y considering the conditioned area of 24’349 m².

Solution set description

The solution set here described is balanced on the specific needs of the Coop Valbisagno reference building and the climate conditions of Genova. Therefore, its replication in other climates or other buildings need to be further investigated.

As the existing building is planned to be demolished and re-built, the baseline is already a new building with a common design. For this reason, the studied solutions sets aim at even reducing the assessed consumption, improving the thermal and visual comfort and promoting the use of environmental-friendly technologies.

To this purpose, the baseline consists of the designed new building with already implemented insulation measures.

Looking at the assessed energy consumption, especially of common areas and food store, the major electricity is used for lighting, refrigeration, cooling and appliances.

The solutions in the following suggested aim at reducing the most consuming demands.

Considering the fact that lighting is responsible for most of the electricity consumption of the mall, we decide to reduce lighting power density through the lamps typology and the control on the intensity (**Solution 1**). The savings can amount to 50 % of the total consumption for lighting. Internal gains due to lighting reduce accordingly and impact significantly the building energy balance with a decrease of cooling need by 25%, but an increase of the heating demand of 60%.

In order to accomplish the new standards on refrigerating fluids, we propose the use of a booster cycle with CO2 for the whole refrigeration system (**Solution 2**) which has lower environmental impact compared to other refrigerants. In terms of energy savings, the impact is not so high, but the innovation consists on the application of this technology in mild climates with same or lower energy consumption with respect to the traditional solutions.

As the heating and cooling loads are covered by a water loop of water-to-water heat pumps, the increase of heating demand can be reduced by recovering waste heat from the refrigeration system and using it in the heat pumps water loop (**Solution 3**).

Natural ventilation through openable windows in the atrium skylights and in the west facade help vent out stale air in the summer, reducing cooling need (**Solution 4**). The connection of opening control to the iBEMS and the integration of inverters automated by the iBEMS would allow to switch off the mechanical ventilation in the common areas when natural ventilation is activated and provides the required air change rates.

In addition to this, the self-consumption of electricity produced onsite by a PV system reduces consumption (**Solution 5**).

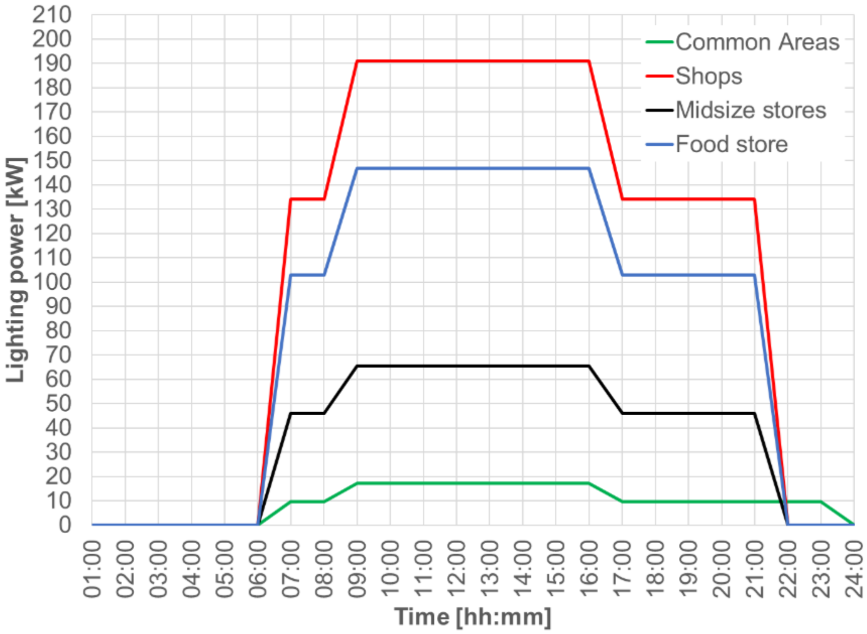
Solution 1: Efficient lighting system and controls

Objective

To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off

Description

Lighting power density is reduced down to 4.5 W/m² in the common areas and galleries and to 18.1 W/m² in the vending area (shops, midsize stores, food store) because of the installation of LED lamps.
Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.



Area of application

Common areas, shops, midsize stores, food store

Expected energy savings

50% reduction of electricity consumption due to lighting
25% cooling need reduction

Expected impact on comfort

Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall.

Interaction with other solutions

By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have an impact on building energy consumption.

Expected investment costs

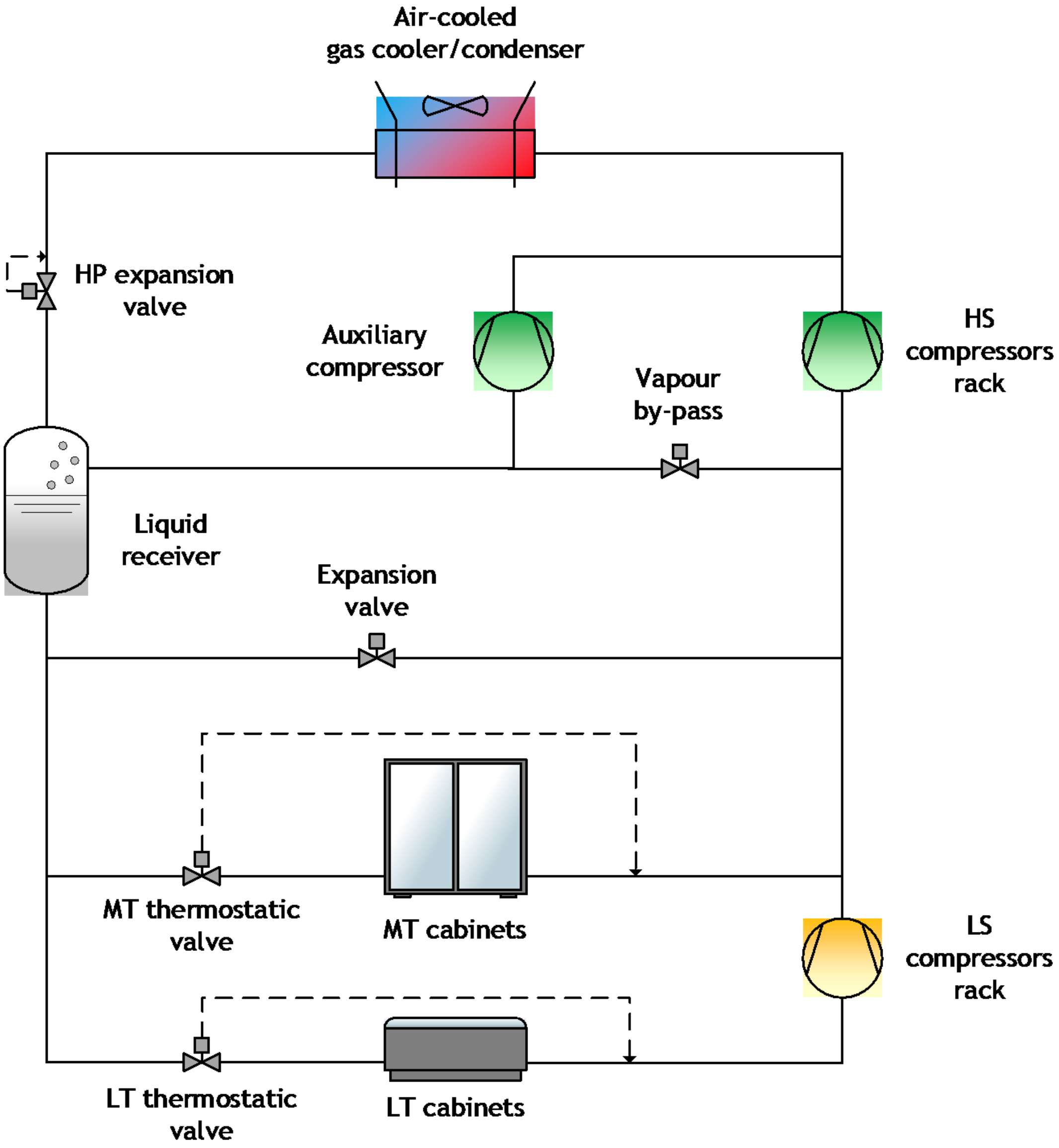
The estimated cost for lamps replacement is 14 €/m². Considering the area interested (10’019 m² for food store and common areas), an investment of 140’266€ is needed.

Solution 2: Refrigeration – CO2

Objective To keep refrigeration consumption at the baseline value achieving environmental advantages thanks to the employment of a natural refrigerant.

Description The use of R744 (CO2) is a leading option for environmental reasons and, thanks to the last technology developments, it is going to be as efficient as the baseline system. Refrigeration with CO2 uses a “natural refrigerant” whose physical properties require special handling. The system pressures are much higher than in conventional systems, but all the components are designed accordingly.

Good experience has been gained especially in the coldest climates, but thanks to additional devices, it is promising in the warmer climates too.



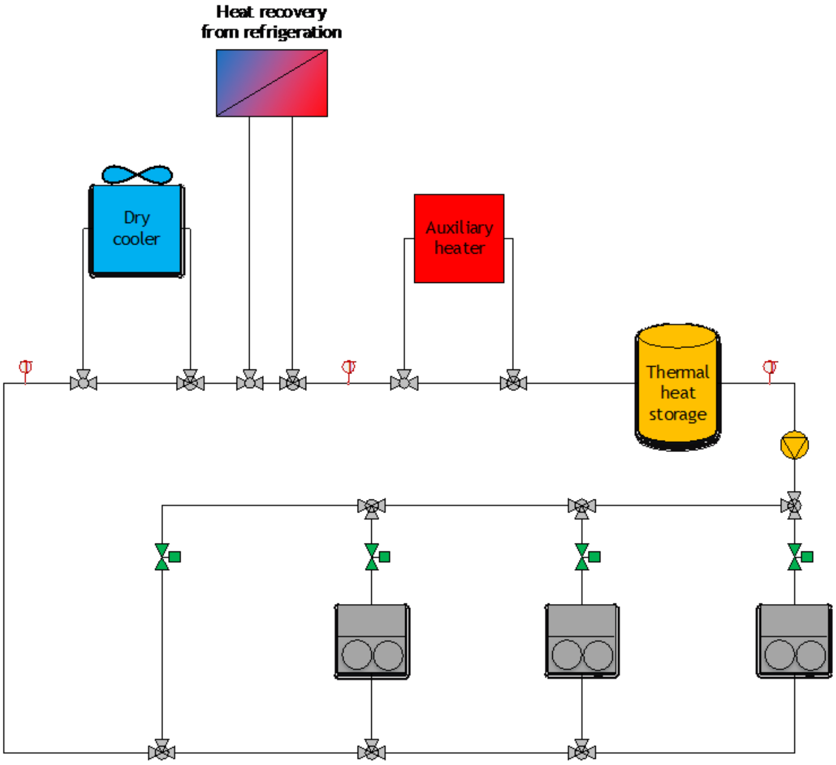
Area of application Food store

Expected energy savings In mild climates, the use of transcritical technologies with respect to the traditional ones does not bring wide savings. If an auxiliary compressor is activated, refrigeration with CO2 can have comparable consumption as the traditional ones or even slightly lower. The advantage of this technology is mainly in terms of environment aspects. The new norms in the refrigerating fluids are moving on the direction of CO2 applications

Expected impact on comfort	No impact on the comfort
Interaction with other solutions	The waste heat of the refrigeration system can be re-used for heating or hot water preparation purposes. In this case, a heat exchange between the two circuits allow to transfer the exceed heat from the refrigeration to the HVAC system.
Expected investment costs	Additional costs compared to a traditional refrigeration system are due to heat recovery, interface with HVAC system, transcritical CO2 plant, ejector, refrigeration cabinets with advanced control mode, adiabatic pre-cooler option. The cost of these additional components has been estimated to 60 k€ for the Coop Canaletto demo. Costs for Coop Valbisagno are still to be estimated.

Solution 3: Heat pumps water loop

Objective	To reduce HVAC system consumption by exploiting waste heat from refrigeration to the heat pumps water loop
Description	A water loop acts as source for a number of electric reversible heat pumps which provide climate control on the various thermal zones. Heat recovery is performed collecting heat from the condenser/gas cooler of the refrigeration system in the cold season and transferred to the heat pumps water loop in order to maintain a certain temperature.

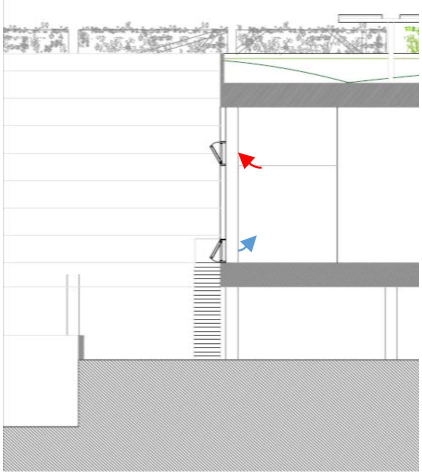


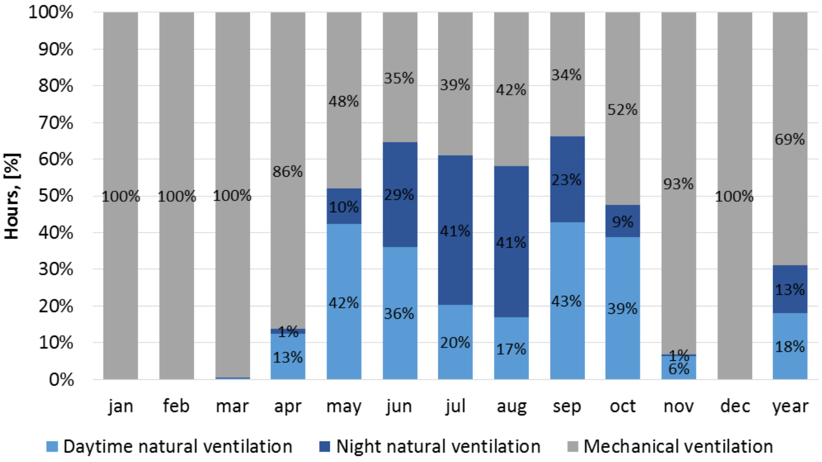
Area of application	Food store, common areas, shops
Expected energy savings	Reduction of heat pumps and auxiliary heater electricity consumption in the cold season. Although in the analysed case the heating season is not predominant, the savings on the heating consumption amount to 12%. Cases with longer heating periods or contemporaneity of different loads can expect higher savings.
Expected impact on comfort	/
Interaction with other solutions	By exploiting waste heat from refrigeration, the energy consumption of the heating generation system is reduced.
Expected investment costs	to be defined

Solution 4: Natural ventilation

Objective	To reduce energy consumption for ventilation and cooling need by foreseeing automated openings to enhance stack natural ventilation in common areas
Description	Natural ventilation through openable windows in the atrium skylights and in the west facade help vent out stale air in the summer. Combining the effect of opened sliding doors and skylight openings can enhance stack ventilation and ventilate/cool the common areas. The connection of opening control to the iBEMS and the integration of inverters automated by the iBEMS would allow to switch off the mechanical ventilation in the common areas when natural ventilation is activated and to introduce a more sophisticated control strategy.

Building section with openings on the west facade (left) and number of natural ventilation working hours (right).





Openings location in the main entrance facade (left) and skylight (right).

Area of application	Common areas: west gallery and main entrance
Expected energy savings	Electricity consumption due to cooling and ventilation reduced by 20%
Expected impact on comfort	Increasing the air velocity within the indoor environment improves the comfort sensation of customers at high indoor temperatures.
Interaction with other solutions	The reduction of cooling demand thanks to the efficient lighting systems and the roof retrofit increase the potential of ventilative cooling
Expected investment costs	The expected investment concerns the automation of 75 openings, the installation of a weather station and indoor temperature and CO_2 sensors. The expected investment cost has been estimated at around 36'780€.

Solution 5: Photovoltaic plant

Objective	to decrease the energy imported from the grid and the CO_2 emissions by generating and self-consuming renewable energy
Description	300 kWp PV plant si installed on the parking canopies on roof parking lots, as shown in the render below.

Area of application	Parking canopies on roof parking lots
Expected energy savings	The yearly simulation performed using consumption data from common areas and food store, gave the results of around 19% of self-production and 100% of self-consumption.
Expected impact on comfort	The PV installation will create shaded parking lots, which are preferred from customers especially during the summer period. Lower ceiling surface temperature improves thermal comfort, especially in the offices on the roof.
Interaction with other solutions	PV plant is sized according to the load peaks estimated after the implementation of all the energy conservation and energy efficiency measures.
Expected investment costs	Costs for PV plant (installation included) on commercial buildings is around 1600 €/kWp. The cost of PV plant on parking canopies (parking canopy included) is estimated at around 2500 €/kWp. Maintenance costs are considered to be 20 €/kWp/year, excluding the first 2 years since generally PV plant are still under guarantee.

Results

This section reports the expected energy savings and costs of the solutions described in par 0 and compared to the actual building energy consumption predicted by the model described in par 0.

Energy and operative costs savings

The graphs in Figure 152 and Figure 153 show the actual yearly final energy and primary energy consumption of the common areas and food store in the baseline model and the potential energy savings of the energy efficiency measures described in previous sections.

The solution set package analysed leads to a reduction of 40% of electricity consumption compared to the baseline case, which corresponds to the renovation project. Up to 26% of energy savings can be achieved by passive and active solutions. Thanks to the PV plant we can have up to 19% of self-production and 100% of self-consumption.

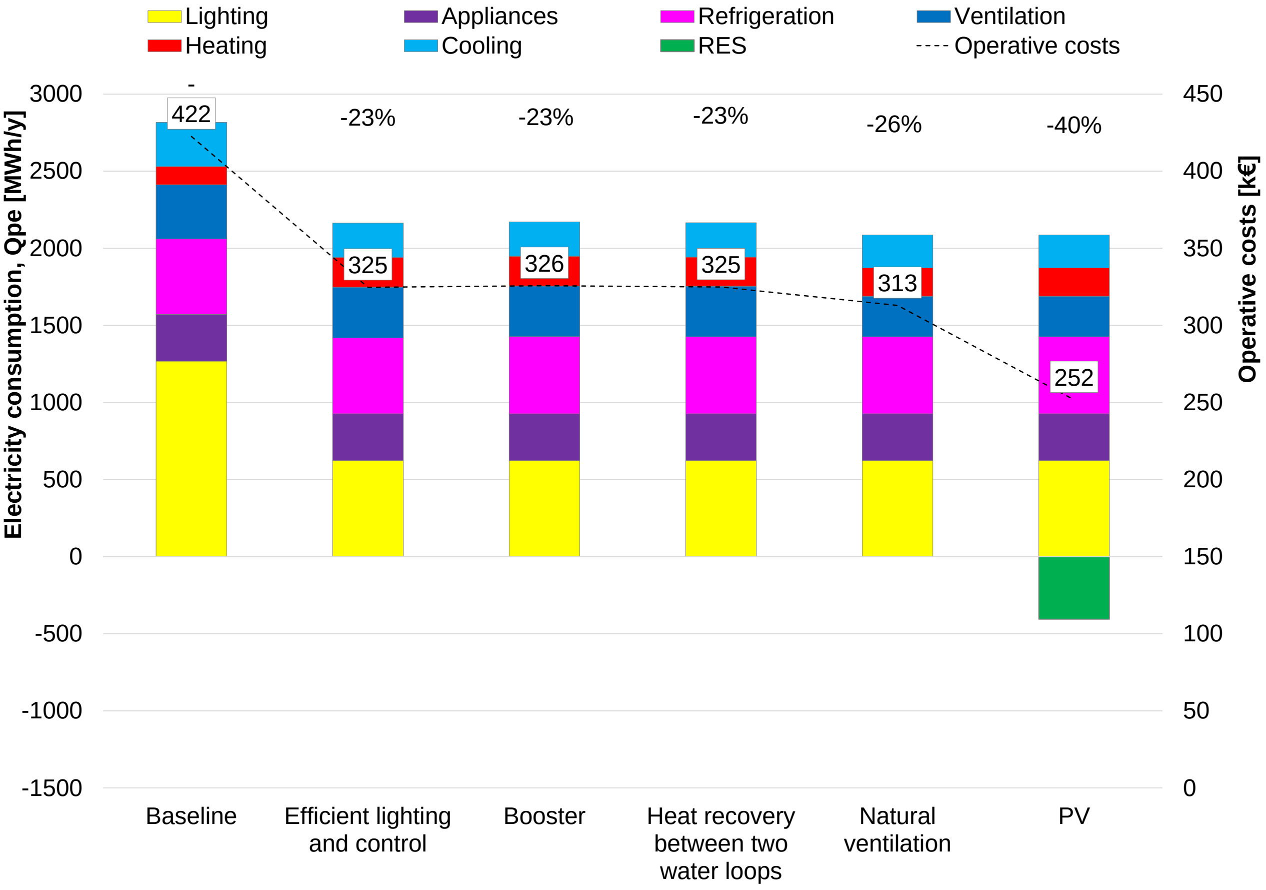


Figure 152. Yearly final energy consumption and operative costs in common areas and food store.

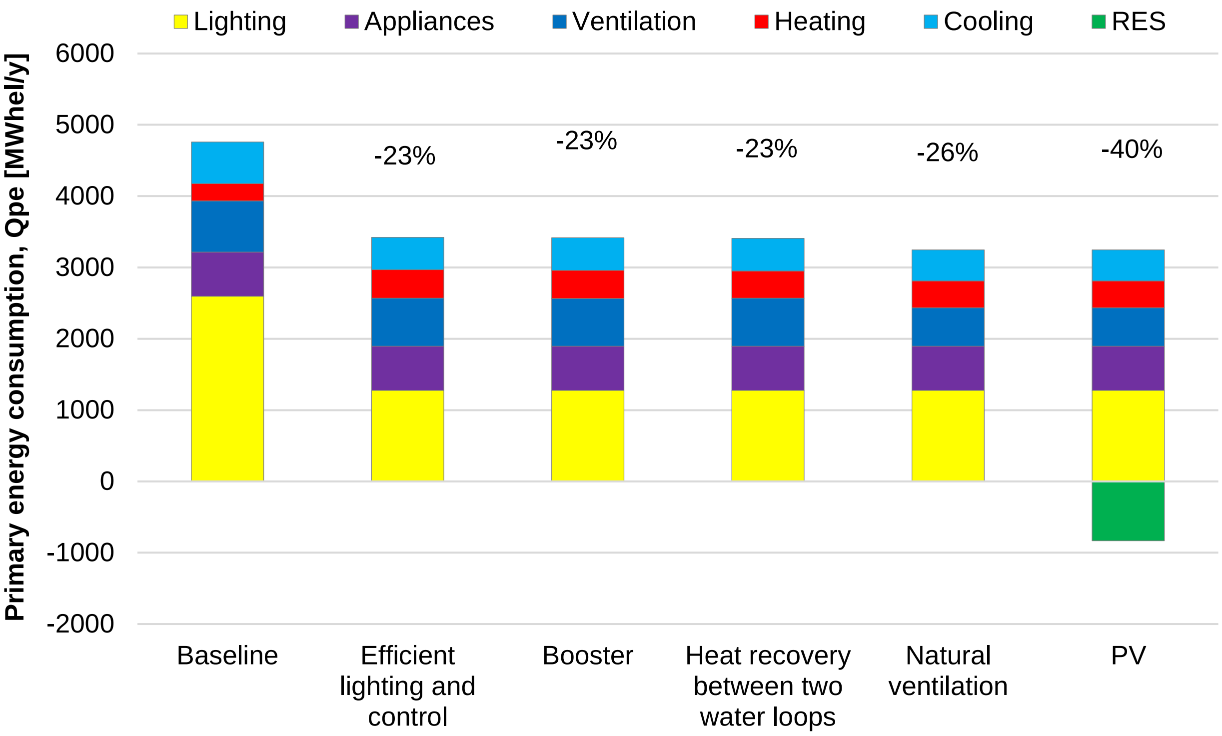


Figure 153. Primary energy consumption in common areas and food store.

Economic analysis

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 1 million €, most of which is due to the PV plant. The total cost of investment of energy conservation and efficiency measures only is estimated at around 526’315 € (incl. tax).

Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 170’000 €/year and the revenues due to the sale of electricity to the grid from the PV plant are estimated as 200 €/year since most of the electricity produced by PV is self-consumed onsite.

Table 22. Assumptions on cost of investment of the solution set.

Equipment	Cost
Efficient and dimmerizable lamps	140’266 €
Weather station	2’000 €
Indoor temperature sensors in galleries	280 €
Window automation	34’500 €
Additional costs for HVAC-refrigeration coupling (estimated)	60’000 €
PV (installation included)	750’000 €
Installation costs (20% of the equipment costs)	35’409 €
Engineers and permitting (10% of the equipment costs)	23’705 €
Total	**1’046’160 €**
Tax (31.4%)	230’155 €

Total cost of investment (incl. tax)	**1’276’315 €**

The economic analysis is based on the assumptions reported in Table 23.

Table 23. Economic analysis assumptions

Assumptions	Value
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	0-8%
Energy costs	
Cost of electricity	0,15 €/kWh
Electricity buy price annual variation	1,0%/year
Electricity sell price annual variation	1,0%/year
Installation ageing	0,5%/year
Operation costs	
Insurance	0,5%
Taxes	1,0%
Maintenance	1,0%
Miscellaneous supplies	0,2%
Contingency	10% from previous concepts
Annual variation	0,5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**.

The results of the cash inflows and outflows for the whole solution set are shown over the 25 years period studied are shown in the graphs in Figure 154 and Figure 155.

The estimated Pay Back Time is expected to be between **7.2 (discount factor 0%) and 11.1 years (discount factor 8%)** depending on the discount factor which can be applied to the investment.

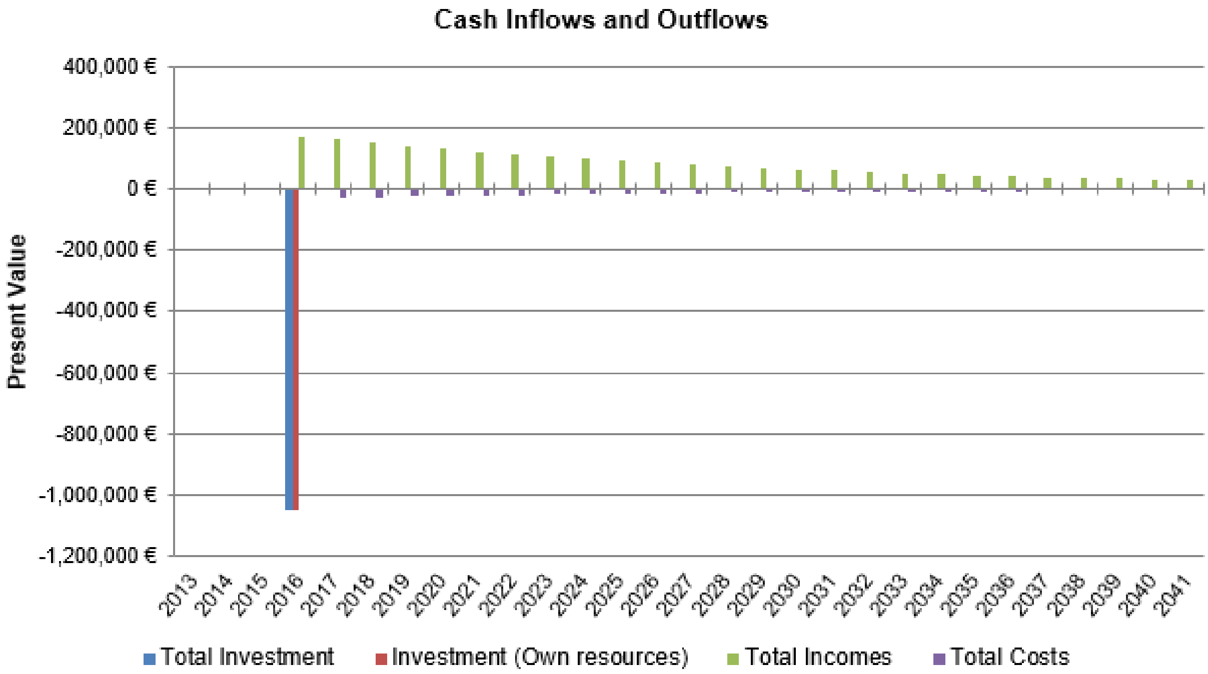


Figure 154. Cash inflows and outflows.

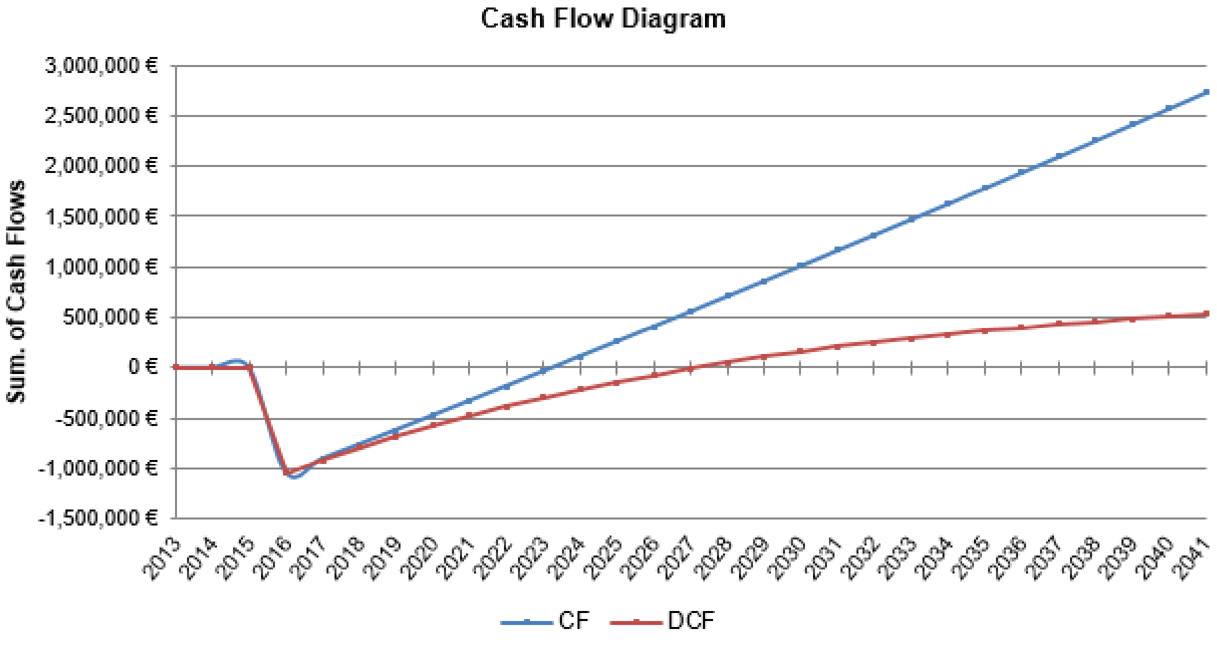


Figure 155. Cash flow diagram

Conclusions

The document presents the proposed solution set for the Coop Valbisagno reference building. Considering that in Coop Valbisagno both common areas and food store are owned and managed by Coop while shops and midsize stores are leased, the proposed solution set mainly focuses on common areas and food store. Since the shopping centre is under a major renovation process which is still in the planning phase, also interventions on HVAC system and cascade systems can be investigated.

The solution set proposed includes:

- Solution 1: efficient and dimmerizable lighting systems and cascade refrigeration
- Solution 2: booster
- Solution 3: heat recovery between HVAC and refrigeration water loops
- Solution 4: natural ventilation
- Solution 5: RES production from PV plant

The Integrated Modelling Environment developed within CommONEnergy project allowed us to take into account the interactions among solutions and to assess the overall energy savings of the solution set package and of each solution stacked on the previous applied ones.

The solution set package analysed leads to a reduction of 40% of electricity consumption compared to the baseline case, which corresponds to the renovation project. Up to 26% of energy savings can be achieved by passive and active solutions. Thanks to the PV plant we can have up to 19% of self-production and 100% of self-consumption.

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 1 million €, most of which is due to the PV plant. The total cost of investment of energy conservation and efficiency measures only is estimated at around 526’315 € (incl. tax).

Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 170’000 €/year and the revenues due to the sale of electricity to the grid from the PV plant are estimated as 200 €/year since most of the electricity produced by PV is self-consumed onsite.

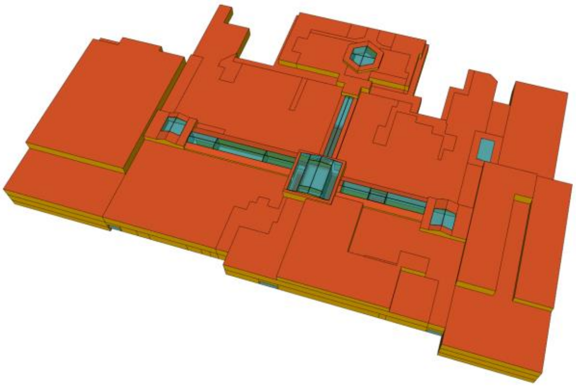
The estimated Pay Back Time is expected to be between **7.2 (discount factor 0%) and 11.1 years (discount factor 8%)** depending on the discount factor which can be applied to the investment.

Brent Cross (London - UK)

Building model

General data	
Gross floor area [m²]	97700
Gross Leasable Area [m²]	84200
Food store vending area [m²]	3680
Tenants vending area [m²]	80400
Common areas and galleries [m²]	13500
Number of opening hours per day [h/d]	10 (11, 6)
Number of opening days per week [d/w]	7
Number of closing days per year [d/y]	3

Thermal zone model



Number of thermal zones	24
Floor height [m]	6.00
Restaurant / office floor height [m]	3.00
Zone typology	**Zone group area [m²]**
Shops	82000
Parking	-
Common areas	9300
Warehouse	-
Office	200
Restaurants	2000
Service areas	4200

Building envelope

Opaque envelope components	U-value [W/m²K]	Solar absorptance [-]
Exterior walls	0.45	0.7
Adjacent walls	2.13	0.6
Exterior roof	0.6	0.6
Ceiling/interior floors	1.619	0.6
Ground floor	1.336	0.6
Glazed envelope components	**Ug [W/m²K]**	**g-value [-]**

Exterior window	2.20
Doors / ports	2.0
Other components	various
Air tightness (ach) [h-1]	3.0 – 7.0
Heat recovery [%]	40
Specific fan power [kW/(m^3/s)]	3.5

	Common areas		Shops		Restaurants		Service		Warehouse		Office	
	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule
People density [pers/m²]	0.14	08:30 – 21:30	0.14	09:00 – 21:00	0.14	09:00 – 21:00	0.14	07:00 – 22:00	0.14	09:00 – 21:00	0.14	09:00 – 21:00
Lighting density [W/m²]	16	08:30 – 21:30	35	09:00 – 21:00	35	09:00 – 21:00	15	07:00 – 22:00	15	09:00 – 21:00	35	09:00 – 21:00
Equipment [W/m²]	7	08:30 – 21:30	10	09:00 – 21:00	10	09:00 – 21:00	7	07:00 – 22:00	10	09:00 – 21:00	10	09:00 – 21:00
	7	21:30 – 08:30	0	21:00 – 09:00	0	21:00 – 09:00	7	22:00 – 07:00	0	21:00 – 09:00	0	21:00 – 09:00
Heating setpoint temperature [°C]	21	07:00 – 22:00	21	07:00 – 22:00	21	07:00 – 22:00	21	07:00 – 22:00	21	07:00 – 22:00	21	07:00 – 22:00
Heating setback temperature [°C]	15	22:00 – 07:00	15	22:00 – 07:00	15	22:00 – 07:00	15	22:00 – 07:00	15	22:00 – 07:00	15	22:00 – 07:00
Cooling setpoint temperature [°C]	26	07:00 – 22:00	26	07:00 – 22:00	26	07:00 – 22:00	26	07:00 – 22:00	26	07:00 – 22:00	26	07:00 – 22:00
Cooling setback temperature [°C]	-	-		-		-		-		-		-
Ventilation rates [m³/(h m²)]	10	07:00 – 22:00	9	07:00 – 22:00	10	07:00 – 22:00	9	07:00 – 22:00	2.5	07:00 – 22:00	9	07:00 – 22:00
Infiltration rates [ach]	0.84	00:00 – 24:00	0.105	00:00 – 24:00	0.105	00:00 – 24:00	0.105	00:00 – 24:00	0.105	00:00 – 24:00	0.105	00:00 – 24:00

Zoning

The building model is divided into 14 thermal zones according to space functions (internal gains level), HVAC systems, orientation and height. In the final energy model, individual shop units were grouped into thermal zones, following the IME methodology developed within the project. This mean that adjacent shops with similar properties and HVAC systems are merged (Figure 156). The internal room height is between 4.0 – 6.0 m in most of the centre. The model comprises 9 Shop zones zoned by location and type to be able to evaluate lighting, heating, cooling and ventilation improvements, 2 Restaurant zones (food courts and cafes) to evaluate comfort in cafes with atrium location, 1 Food store (Waitrose) and 3 Anchor stores (52 % of GLA).

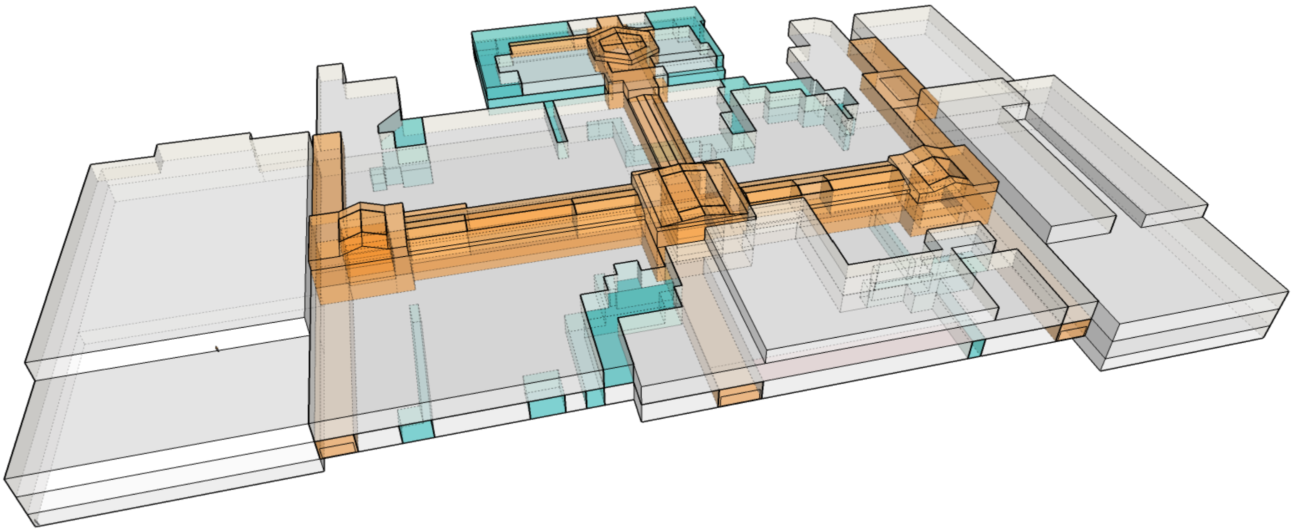


Figure 156. Model illustration of the areas, grey are gross leasable area of shops, blue show service areas (such as staircases, elevators etc.) and orange is common areas.

Even though the internal divisions are simplified from the actual floor plan, the gross leasable unit and external facade areas are respected. This simplification means that units may share less, little or too much internal walls with adjacent zones. In relation to establishing the magnitude of the heat transmission between the zones through internal partitions, the air exchange between units are a significant part of heat exchange occurring between zones, which has consequences for estimating heating, cooling and temperature distribution within the centre.

In the baseline model air exchange is not considered between zones. As a result, temperatures may vary greatly between the zones and that heating and cooling may occur at the same time in the simulation. Heat transmission (conduction) through internal walls, will account for some of the exchange of heat between zones, evening out temperatures. By modelling internal partitions with poor insulation level, this effect may also compensate for the heat exchange which could be modelled through air exchange paths. However, other physical effects normally cause temperature difference between parts of a centre and may lead to heating and cooling at the same time. The dominant airflow direction between zones, placement of ventilation inlets and outlets, thermostat placement and HVAC control algorithms, as well as the effect of additional partition walls between zones.

Simulation settings

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

Two weather files are used for the analysis:

- **Typical Meteorological Year (TMY)**, which derives from Meteonorm database (Meteotest, 2015) and is representative of the standard weather conditions.

- **Actual Metereological Year (AMY)**, which derives from Weather Analytics database (Meteotest, 2015) and reports the actual weather conditions over 2014.

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling set-points all the time.

Table 24. Simulation settings

Timestep	15 min
Simulation start	January 1st
Simulation stop	December 31st
Preconditioning period	1 month
Simulation mode	Unlimited power

Actual building energy consumption

The graphs in Figure 157 to Figure 159 show the simulated and measured energy consumption.

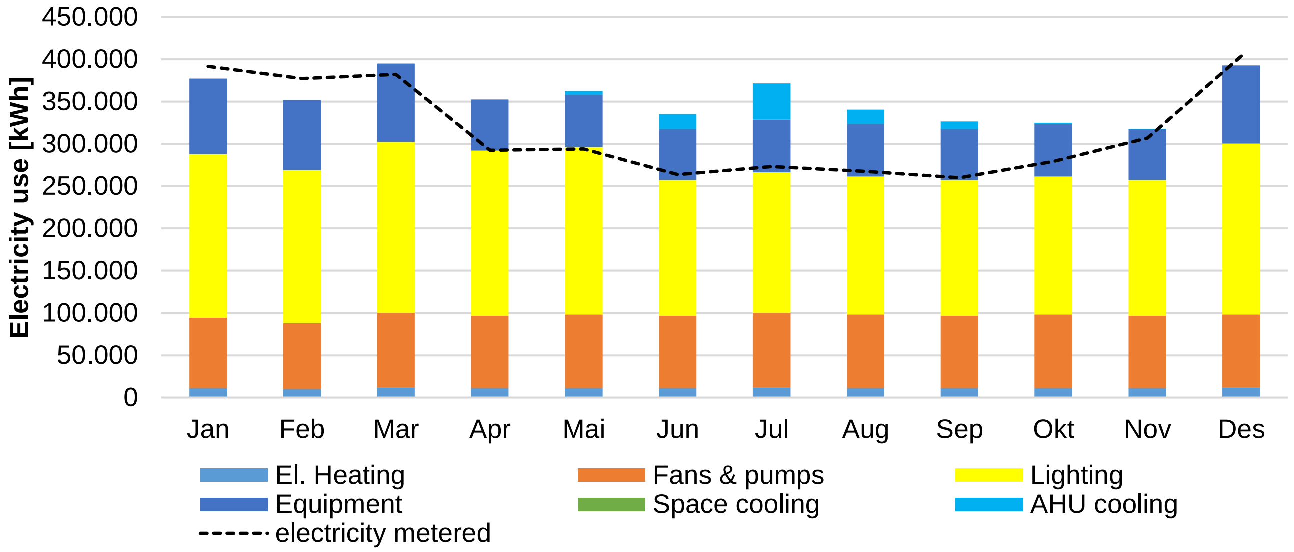


Figure 157. Predicted and measured landlord electricity use.

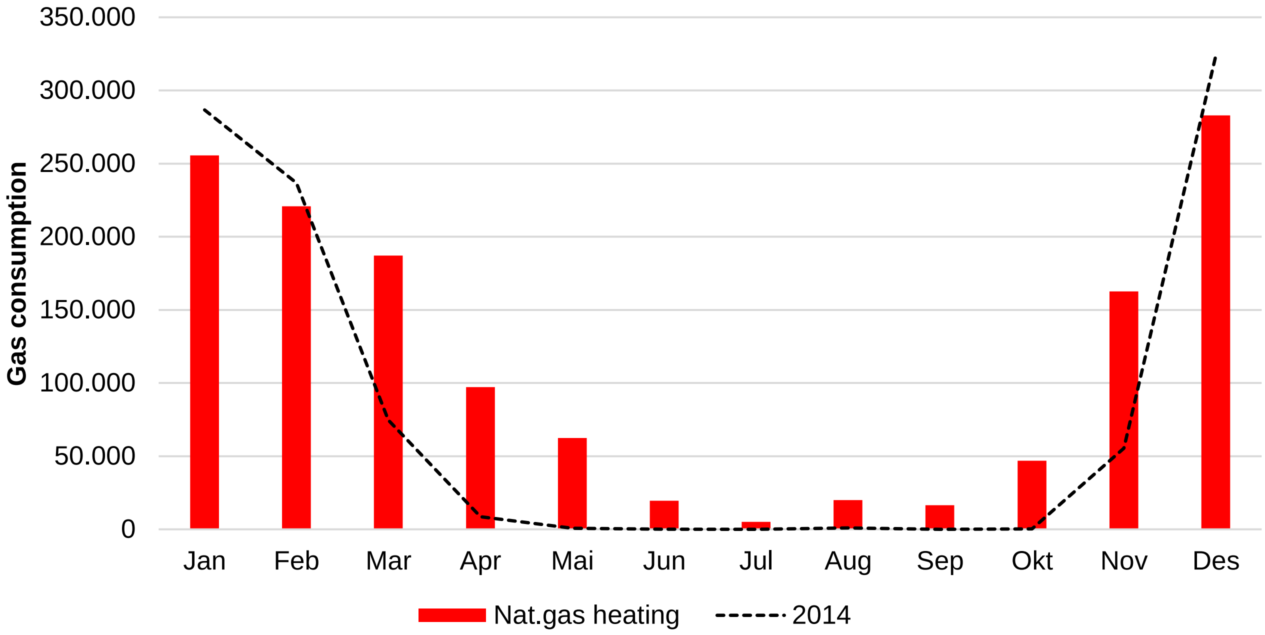


Figure 158. Predicted and measured landlord gas consumption

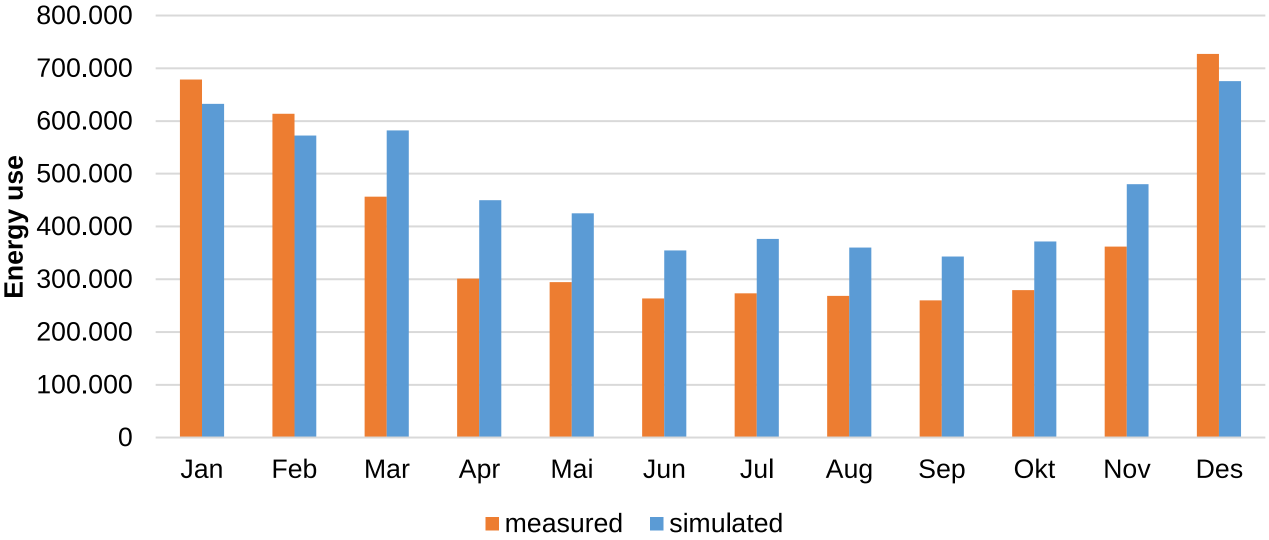


Figure 159. Predicted and measured energy use.

Solution sets description

The solution set here described is balanced on the specific needs of the Brent Cross reference building and the climate conditions of London. Therefore, its replication in other climates or other buildings need to be further investigated.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decide to reduce lighting power density **(solution 1)**. Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need by 84%, but increasing the heating demand.

The installation of energy efficient appliances is seen as an important further step to reduce energy use in the shopping centre (**solution 2**).

Finally, the installation of PV plant (750 kWp) on the roof **(solution 3)** will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. Table 25 provides an overview of the selected solutions. Each solution is described in more details below.

Table 25. Summary of solutions

Solutions		measures
1	**Lighting**	Various measures for CMA, shops, restaurants, service areas
2	**Appliances**	Energy efficient appliances, escalators etc.
3	**RES – PV**	45000m² PV plant (5MWp)

Solution 1: Efficient lighting system and controls

Objective To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off

Description Lighting power density is reduced down to 4.5 W/m² in the common areas and galleries and to 18.1 W/m² in the vending area (shops, midsize stores, food store) because of the installation of LED lamps.

Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time. The concept of the zonal spatial distribution consisting of a comprehensive set of solutions that was applied that let us expect savings in energy demand of around 60% against the initial situation. These measures include:

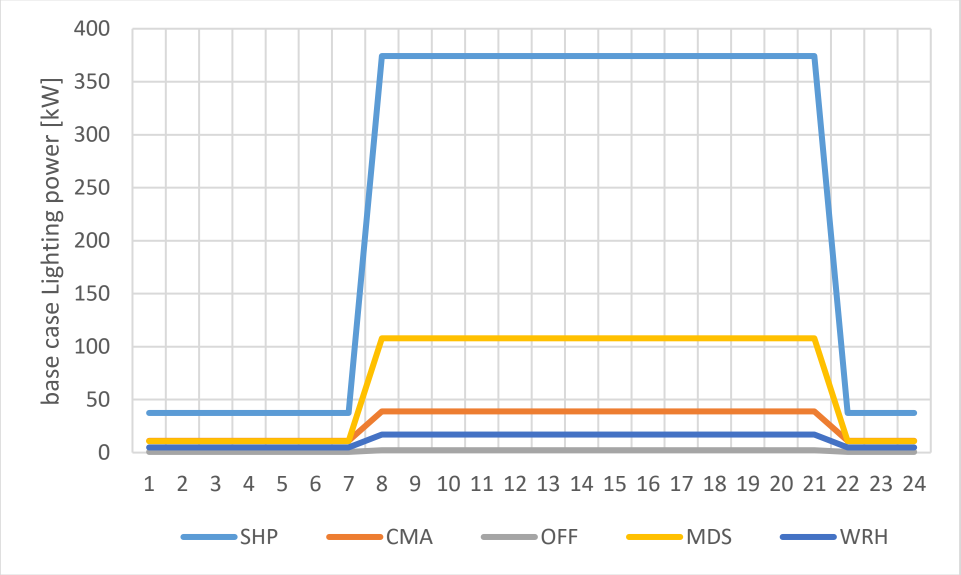
- Application of newly developed LED high lumen retail wallwasher which precisely illuminates merchandise with high efficacy and homogeneity. Glare will be reduced due to very good longitudinal glare control. Beam angle was extended to 120° in order to illuminate not only the merchandise wall but also the area in front to enable optimal examination of goods by customers.
- Introduction of a evening scenario with warm-white light color of 2700 K und reduced intensity. This lighting scene considers human biorhythm as the indoor room atmosphere is coupled with the natural outdoor lighting environment.
- Sophisticated control and monitoring strategy that enables highly differentiated space areas.

Opening hours

Starting from the strategies that BLL proposed for the City Sud democase, the schedules and the values were used as a retrofit solution for the reference building.

According to BLL artificial lighiting design the schedule is basically characterized by four period within a day:

- Out of Operation: is the period in which the shopping centre is closed (at night, Sunday and during holidays)
- Preparation Hours-Morning : is the period before the public opening of the shopping centre. During this time some internal activities are performend (e.g. cleaning,restock of supormarket, shops,ecc…)
- Business hour corresponds to the public opening hour of the shopping centre
- Preparation Hours-Evening : same of the morning, is the period just after the closing to the public of the shopping centre



Area of application Common areas

But also applicable for shops, midsize stores, service areas.

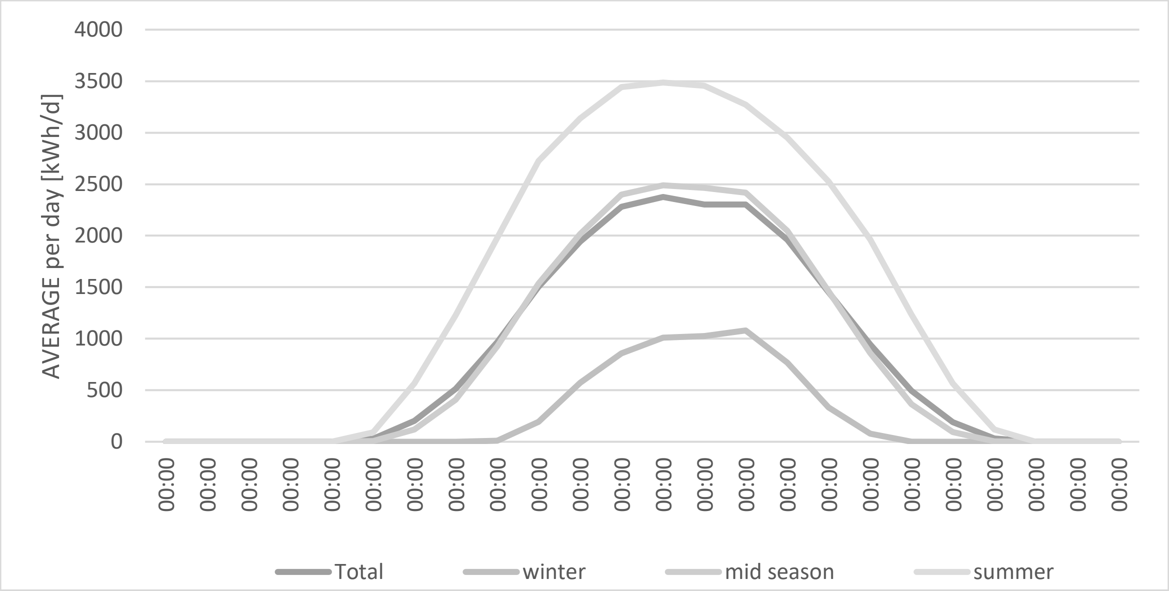
Expected energy savings	57% reduction of electricity consumption for lighting 40% cooling need reduction
Expected impact on comfort	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping centre.
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have an impact on building energy consumption. Here, an increase in heating demand of factor 2 is expected (note the relatively low heating demand in the base case).
Expected investment costs	1.7 mil €

Solution 2: Appliances

Objective	To reduce energy consumption for appliances by exploiting existing systems.
Description	Appliances in shopping centres consist of • Distribution Transformers • IT Equipment (non-data centre) • Water Treatment/Distribution • PCs (Laptops, Desktops, Monitors) • Cash machines • Kitchen Equipment (in restaurants) • Refrigerators/Freezers (in supermarkets) • Video Displays/Boards • Security Systems • Vending machine • Escalators • Elevators • Security lighting The appliances will be exchanged in maintenance cycles with high efficiency products.
Area of application	Common areas, shops, offices, restaurants, warehouse
Expected energy savings	It was assumed that power consumption is appr. 3608 MWh per year (10W/m^2 in the shops (and 1 W/m^2 during non-operation hours) and 7W/m^2 in the CMA (during operation and non-operation hours)) and can be reduced by energy efficient appliances to 5W/m^2.(and reduced to 1W/m^2 during non-operation hours in shops and common areas). This would result in electricity savings of 4629 MWh per year.
Expected impact on comfort	The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.
Interaction with other solutions	The reduced internal heat gains will reduce cooling demand and increase heating demand.
Expected investment costs	727 235.00 €

Solution 3: Photovoltaic plant

Objective	Peak shaving by PV (optional + battery system)
Description	55000 m² PV system (almost) horizontally installed on roof (9MWp). (optional: Battery system installed in technical room.)



Area of application	Roof
Expected energy savings	Almost 8700MWh electricity production which can be used to reduce electricity demand in the shopping centre. If the PV is combined with a battery energy storage system, advantageous situation are for suppling a dedicated load (e.g. lighting system) or shave the peak (only to smooth the energy profile and not strictly related to the energy prices during the day).
Expected impact on comfort	Less overheating during summer due to reduced internal heat gains.
Interaction with other solutions	Load profiles will change due to other solutions. Size of batteries (storage) will depend on mismatch between (new) load and production.
Expected investment costs	See results section

Results

Energy and operative costs savings

The graph in Figure 160 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described above. The figures below show primary energy savings of the solution set based on solution for lighting, appliances and RES. The primary energy for this solution set could be reduced by 75%.

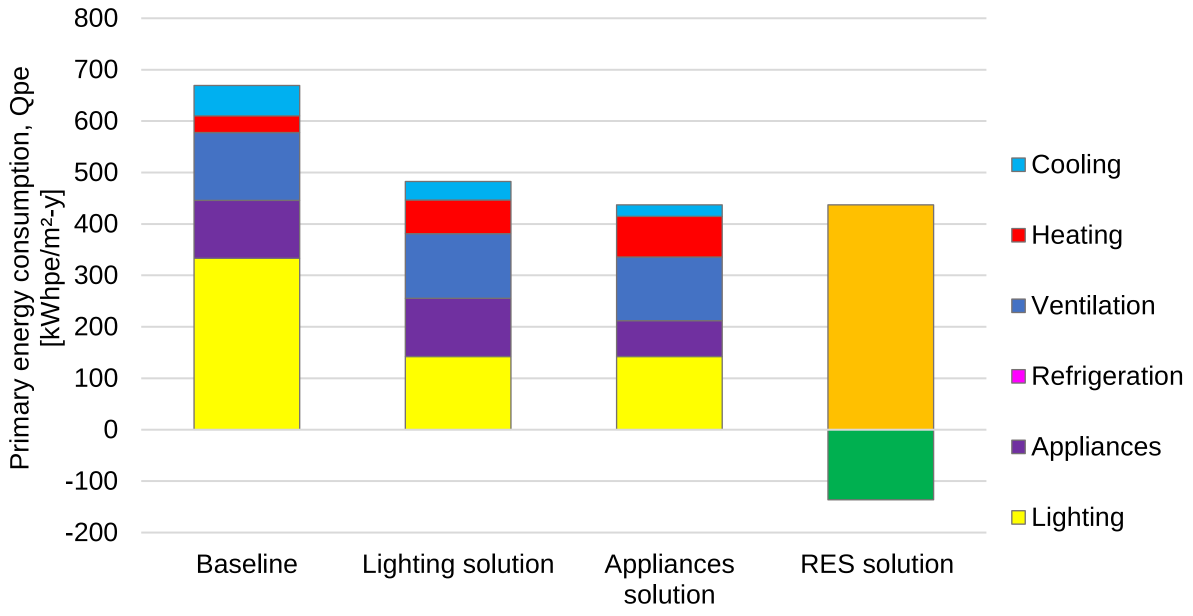


Figure 160. Yearly primary energy use and possible savings of 75% compared to baseline.

Economic analysis

The economic analysis is based on the assumptions listed in Table 26.

Table 26. Economic analysis assumptions

Assumptions	Value
Year of reference (year 0)	2017
Analysis period	25 years
Discount factor	3%
Energy costs	
Cost of gas	…..
Cost of electricity	0.20 €/kWh
Cost of district heating	-
Electricity buy price annual variation	1,0%/year
Electricity sell price annual variation	1,0%/year
Installation ageing	0,5%/year
Operation costs	
Insurance	0,5%

Taxes	1,0%
Maintenance	1%
Miscellaneous supplies	0,2%
Contingency	10% from previous concepts
Annual variation	0,5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**.

The results of the cash inflows and outflows is shown over the 25 years period studied are shown in the graphs in Figure 161 and Figure 162.

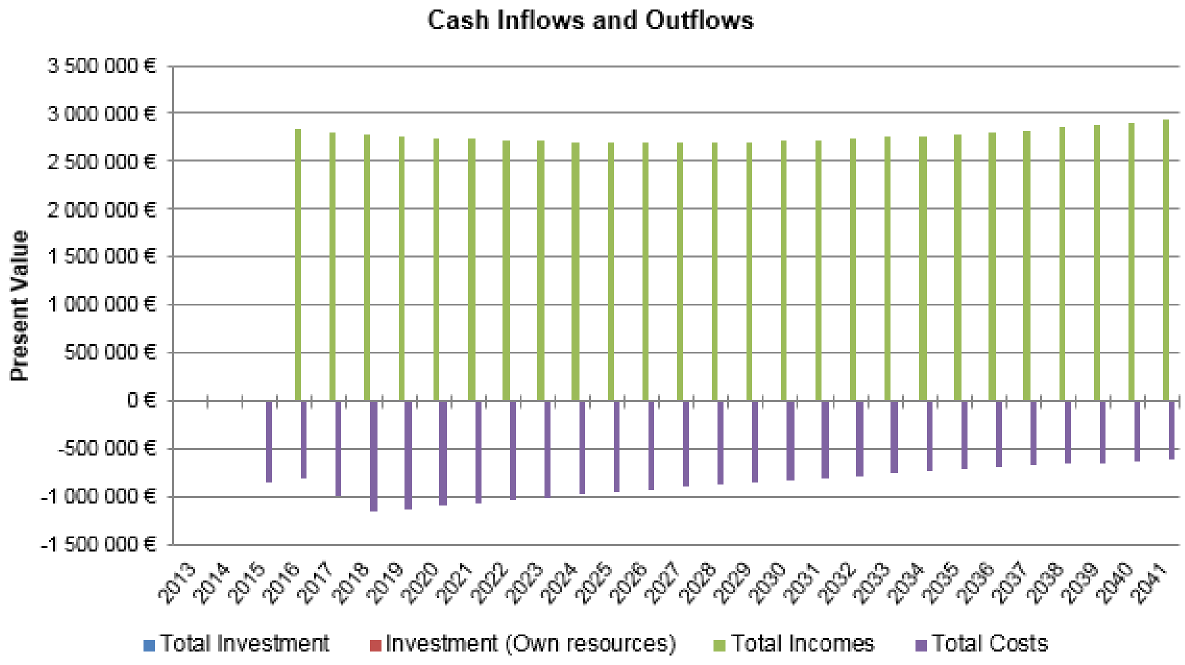


Figure 161. Cash inflows and outflows

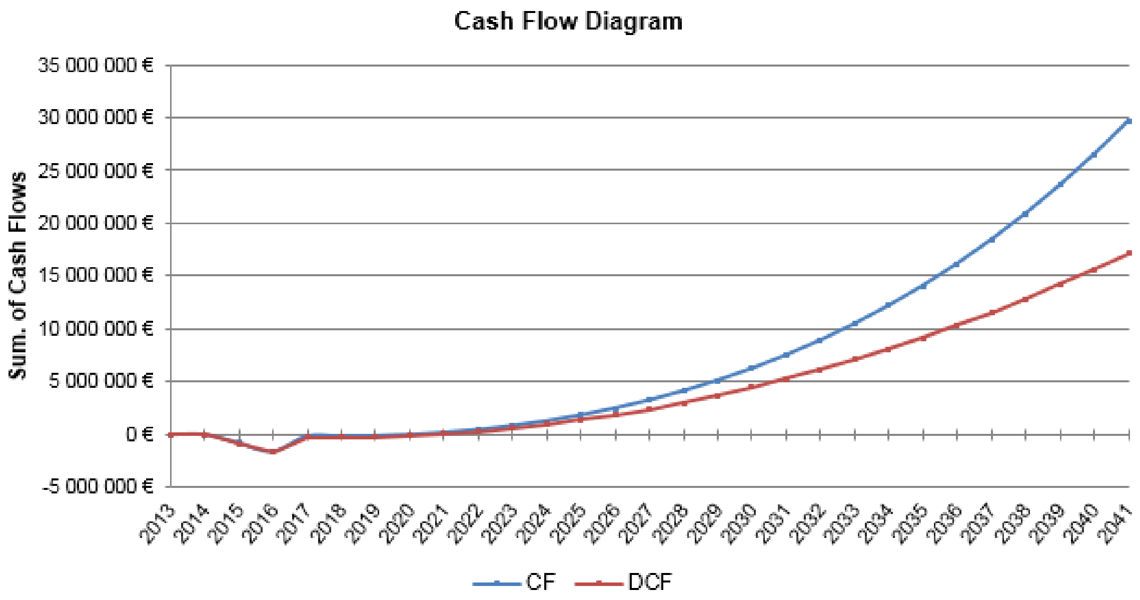


Figure 162. Cash flow diagram

Table 27. Economic evaluation summary

Solution set	Investment [€]	Operation costs savings 1st year [€]	DPB [years]	NPV [€]	ROI [%]
a	10 851 105	1 876 000	7	17 152 968	23.49
b	16 295 040	2 848 000	19.37	5 720 895	8.20

Conclusions

The building energy simulation model was set-up to enable us to predict energy consumption and loads on hourly basis, as well as indoor conditions for each of the reference building. With the help of the model it was possible to for define management strategies. We used the actual consumption data, when available, for plausibility check to validate the simulation results usability.

We have tested and quantified the potential energy savings of energy efficiency measures including envelope elements, efficient lighting systems, daylighting systems, ventilative cooling, HVAC+R layouts, renewable energy production and storage systems. Furthermore, we were also analysing the energy efficiency measures from economical point of view since we aim at defining cost-effective and energy efficient solutions for the retrofit of shopping centres.

The solution set proposed for the retrofit consists of the following measures:

- Lighting: Various measures for CMA, shops, restaurants, service areas
- Reduction of installed power for lighting
- Appliances: Energy efficient appliances
- Reduction of installed power for escalators, etc.

- Renewable Energy Supply

- PV: PV plant (5.5MWp)

Solution a:
A PV system size of 5.5MWp provides a DPB of 7 years. PE savings are 55% compared to the baseline.

Solution b:
If 75% PE savings want to be reached, the PV system has to be enlarged to 9Mwp. The investment costs are with 16.4 mil € high but it should be considered the size of the shopping centre. The expected payback period is below 20 years. Remarkable is the ROI of 8% which could provide an opportunity for investment.

Katané (Catania - Italy)

Building description

The shopping mall Katané in Catania (Sicily) owned by IGD and Ipercoop Sicilia opened in 2009. A two floor gallery with more than 60 retail units offers a GLA of 27.521 m² of which 8.000 m² are dedicated to a hypermarket. The hypermarket offers all kind of convenience goods such as fresh food and delicatessen, pharmacy, textile, household goods and multimedia. The hypermarket is currently developing an "investment and management low cost" design with more attention to reduce building' and management costs, lower water consumption in lavatories and service areas and a reduction of the warehouses area. The air-conditioned gallery is equipped with a high efficiency heating plant including a heat pump. The roof of the commercial centre is a private parking area for the shopping mall workers.

Figure 163. View of the main facade of the shopping mall.

Location

The building is located in the town of Gravina di Catania (Italy). It is in Sicily, on Etna mountain's south slope at 280m above the sea level.

Figure 164. Satellite view. Source: Google map.

The shorter building axis is rotated of 27.5° from absolute north. Therefore, the main building facade is oriented towards south- east.

Building model

Here follows the description of the reference building model which refers to the actual state of the building. The energy savings potential of the proposed solution will be calculated according to the energy performance predicted by this reference model.

Weather file

Two weather files are used for the analysis:

- Typical Meteorological Year (TMY), which derives from the interpolation of historical data series (2000-2009) of three weather stations located in Sicily and which are part of the Meteonorm database (Meteotest, 2015) Gela, Messina, Palermo.

- Actual Metereological Year (AMY), which derives from Weather Analytics database (Meteotest, 2015) for the specified building location over 2014.

The TMY weather file is representative of the average weather conditions and therefore it is applied to assess the baseline energy consumption and the energy reduction potential of solution sets.

The AMY weather file reports the actual weather conditions over 2014 and it is applied to calibrate the model together with the consumption data of 2014.

The graphs in Figure 165, Figure 166 and Figure 167 reports a comparison among the two weather files in terms of dry bulb temperature, total horizontal irradiance and relative humidity respectively.

The dry bulb temperatures in the AMY weather file are colder than in the TMY weather file with higher frequencies of dry bulb temperatures around 10°C-13°C and 19-20°C. The horizontal irradiance values are quite similar except for the values below 100 W/m², which are greater in the TMY file compared to the AMY file. Relative humidity distribution has higher values in the range below 55% and above 90% for the AMY file compared to the TMY file. This means that in 2014 more extreme humidity conditions were experienced compared to the standard.

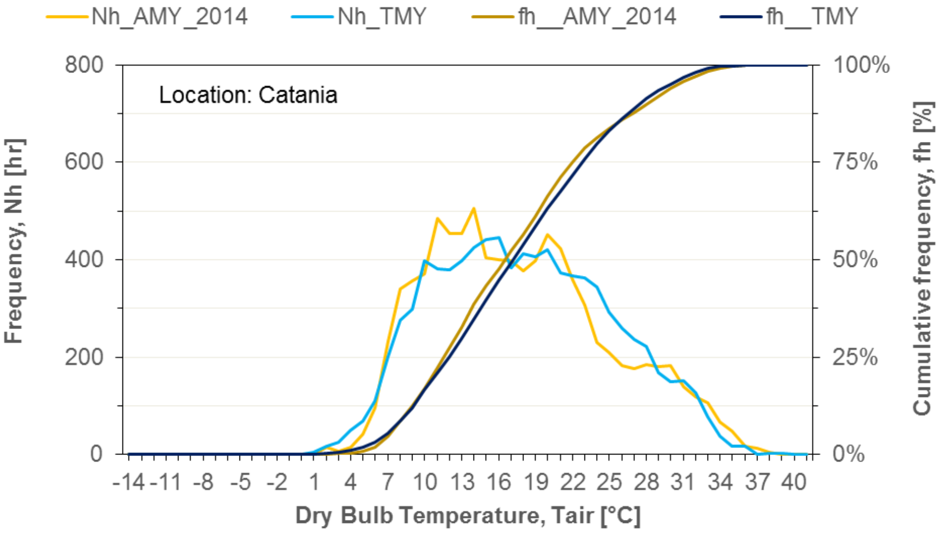


Figure 165. Air temperature distributions of the AMY and TMY weather files.

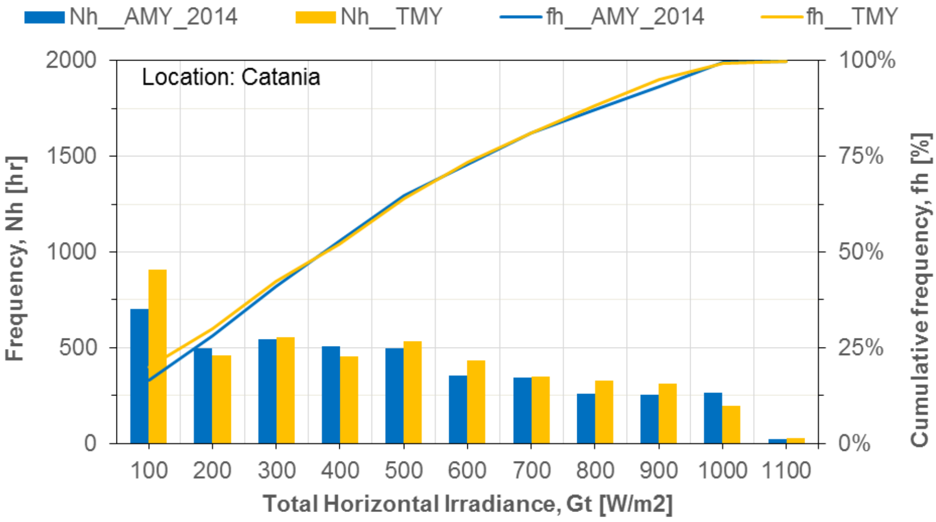


Figure 166. Global horizontal radiation distributions of the AMY and TMY weather files.

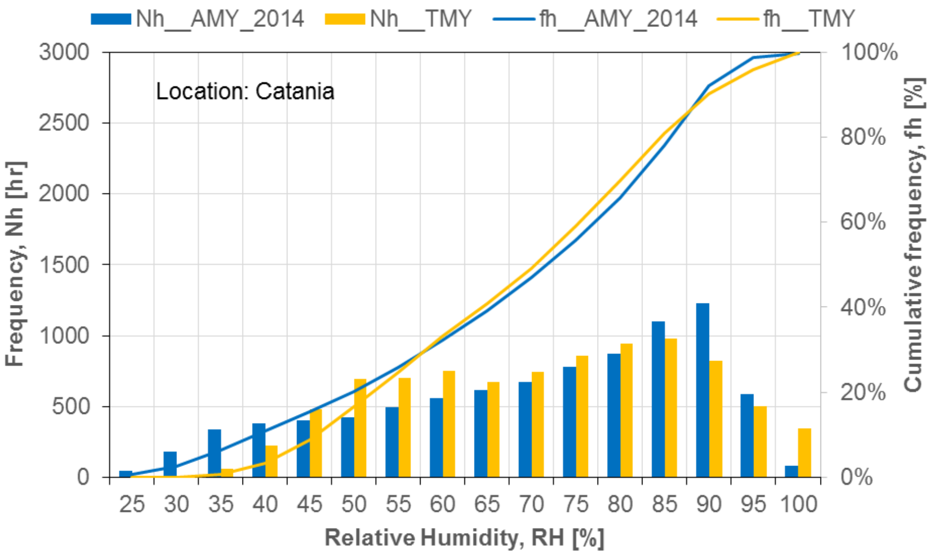


Figure 167. Air relative humidity distributions of the AMY and TMY weather files.

Zoning

The building model is divided into 25 thermal zones according to space functions (internal gains level), orientation and height. In the ground floor there is only parking area. First floor is half used as parking area, opened to outdoor, and the rest is occupied by the mall area.

Hypermarket is located at the second floor (L2_M_FDS), where there is also a shops' gallery connecting two stairwell shafts with skylight on top. In order to account, although in a simplified way, for thermal stratification, we divided the two stairwell shafts into two (L1_N_CMA_AN1, L1_N_CMA_AN2) and three airnodes (L1_S_CMA_AN1, L1_S_CMA_AN2, L1_S_CMA_AN3) respectively, so that thermal zones height is lower than 4 m.

On the roof there are two thermal zones, L3_W_OFF and L3_S_OFF, representing the shopping mall's and hypermarket's offices, respectively.

Thermal zoning is represented in Figure 168 and Figure 169. Figure 170 shows the Sketchup model of the building.

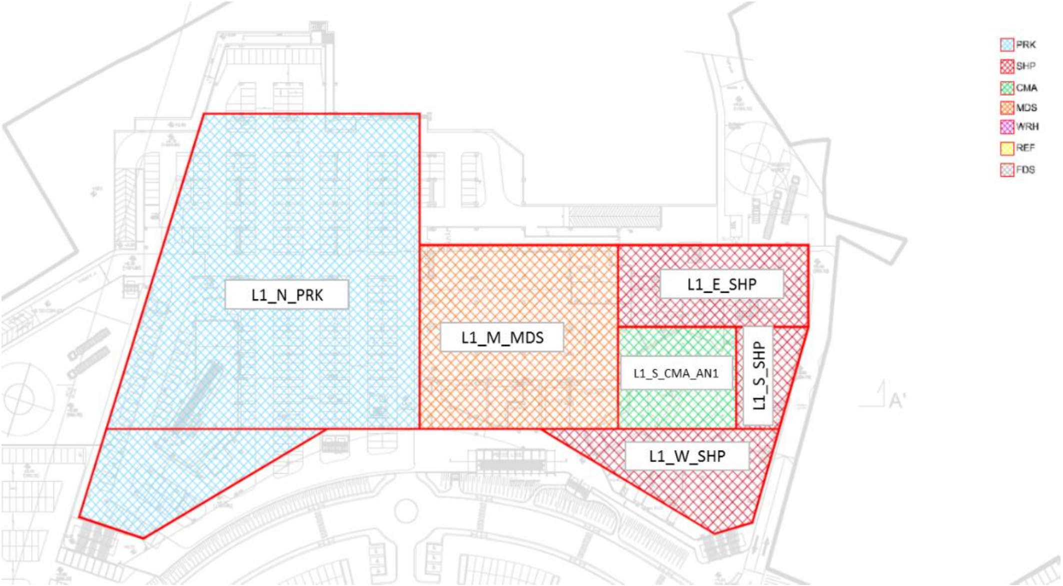


Figure 168. First floor plant with thermal zoning.

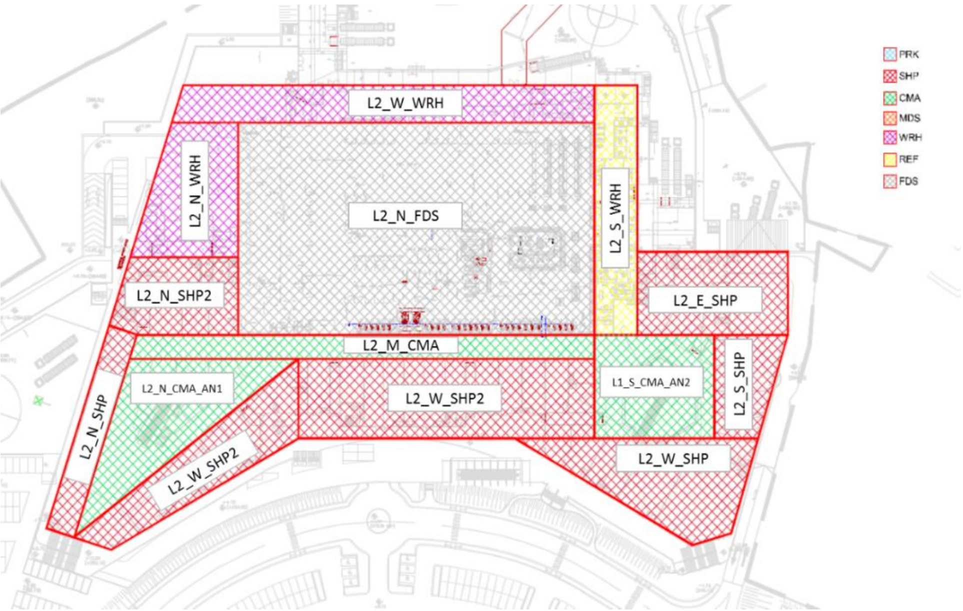


Figure 169. Second floor plant with thermal zoning.

Table 28 reports the Zone ID and their main geometry dimensions as well as the airnode capacitance set. For nomenclature, please refer to D4.1 (Dipasquale C., 2016).

Table 28. Zone data summary.

	Zone ID	Nr of airnodes	Area [m]	Height [m]	Volume [m³]	Capacitance [kJ/K]
1	L2_W_SHP	1	1449	5.80	8406	100875
2	L1_S_SHP	1	736	4.00	2945	35342
3	L1_S_CMA	3	1295	17.80	23059	276704
4	L1_M_MDS	1	3614	4.00	14457	173479
5	L3_W_OFF	1	389	3.00	1166	13995
6	L2_W_WRH	1	1946	5.80	11285	135425
7	L2_S_WRH	1	1076	5.80	6243	74910

8	L2_N_SHP	1	628	5.80	3645	43740
9	L2_S_SHP	1	671	5.80	3892	46707
10	L1_W_SHP	1	1350	4.00	5402	64821
11	L1_E_SHP	1	882	4.00	3528	42341
12	L0_PRK	1	20277	2.70	54748	656975
13	L2_N_WRH	1	1166	5.80	6762	81143
14	L2_N_CMA	2	1776	11.20	19888	238654
15	L2_N_SHP2	1	801	5.80	4643	55721
16	L2_E_SHP	1	1249	5.80	7243	86915
17	L1_N_PRK	1	10939	4.00	43756	525072
18	L2_M_CMA	1	1232	5.80	7146	85747
19	L2_M_FDS	1	8106	5.80	47013	564160
20	L3_S_OFF	1	889	3.00	2667	32006
21	L2_W_SHP2	1	1725	5.80	10004	120050
22	L2_W_SHP3	1	1064	5.80	6168	74020

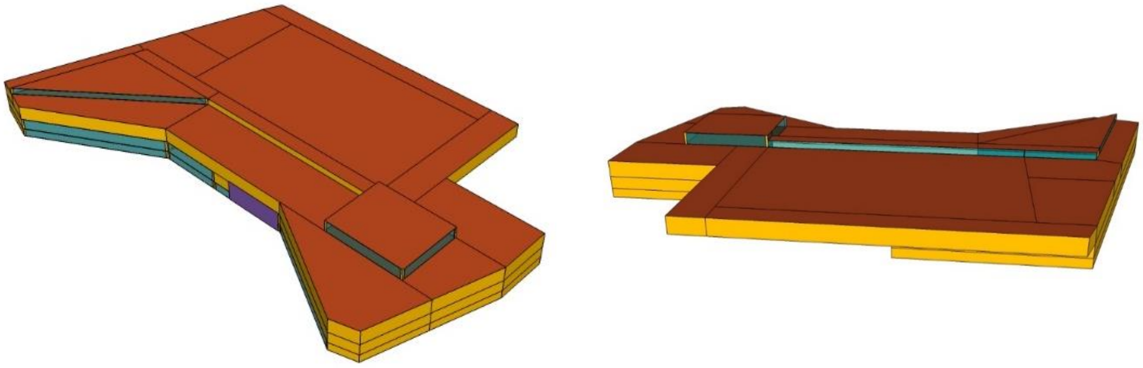


Figure 170. South-west (left) and north-east (right) view of the building SketchUp model

Building envelope

The exterior walls and the roof are in precast concrete with 10 cm external insulation. Since the walls are painted in ochre colour, we considered a 0.7 solar absorptance. The exterior roof is partially occupied by a parking lot and therefore paved (Figure 171). The rest of the roof is covered by a bitumen waterproofing membrane (Figure 172, Figure 173).

Figure 171. View of the parking on the roof.

Figure 172. Skylight over the northern stairwell shaft and gallery skylight.

Figure 173. Skylight over the southern stairwell shaft.

No detailed information about exterior windows are available. Therefore, a common double glazing window with no shading elements is considered. Table 29 and Table 30 report the thermal properties of the envelope set in the simulation.

Table 29. Thermal properties of the building envelope.

Construction ID	Surfaces	U [W/m²K]	Solar absorptance
EXT_WL	Exterior walls	0.823	0.7
ADJ_WL	Adjacent walls	2.134	0.6
EXT_RF	Exterior roof	0.400	0.6
ADJ_CL	Ceiling/interior floors	1.619	0.6
GRD_FL	Ground floor	1.336	0.6

Table 30. Thermal properties of the glazed surfaces.

Window ID	Surfaces	U_g [W/m²K]	U_f [W/m²K]	g-value
EXT_WD	Exterior window	2.83	3	0.755

Heating and cooling setpoints

The heating demand of the market has been calculated by imposing a set point temperature of 21°C from 9 am to 9 pm and a setback temperature of 15°C during every day. The cooling set point temperature varies between 23°C and 26°C, depending on outdoor temperature (see Figure 174), from 9 am to 9 pm. The heating and cooling system is turned off during the night. No additional air humidification is considered during the winter time.

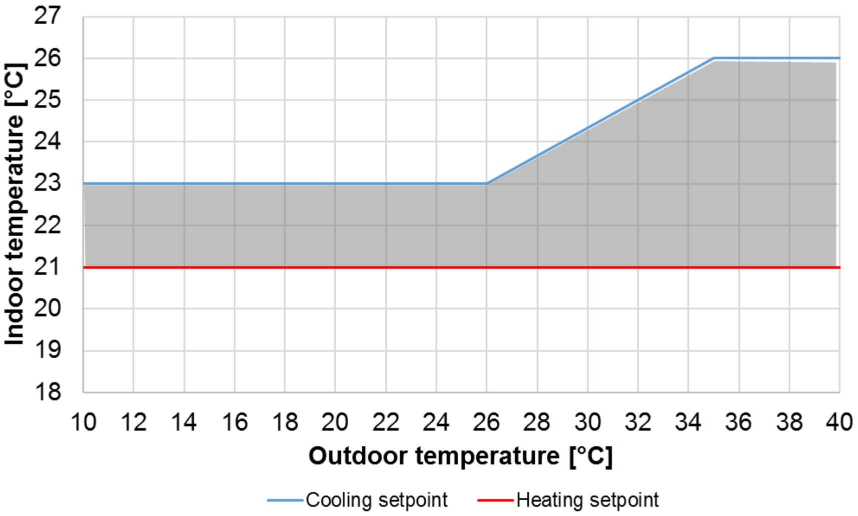


Figure 174. Heating and cooling setpoints.

Infiltration

The infiltration rates are calculated according to the basic equation by Coblenz and Achenbach 1963.

$$I = I_{design} * (0.606 + 0.03636 * |T_{zone} - T_{amb}| + 0.1177 * v)$$

where

I_{design} = design infiltration rates [ach]

T_{zone} = zone temperature [K]

T_{amb} = ambient temperature [K]

v = wind velocity [m/s]

The design infiltration rates are set to 0.5 ach in each zone of the model. In the parking zones, the infiltration rates are set to 10 ach in order to simulate their semi-outdoor environment feature.

Ventilation

Ventilation rates are set according to the information provided by IGD on HVAC plants.
Rooftop units for common areas and midsize stores provide fresh air which is partially mixed if the outdoor temperature falls below 13°C. In this case 70% of the supplied airflow is mixed with 30% of fresh air.
The airflow in the shops is provided by AHU with heat recovery (60% efficiency). Whereas office and warehouse zones are supposed to have no recirculation nor heat recovery.

Table 31. Ventilation rates.

ID	Description	Ventilation rate [1/hr]	Recirculation rate [1/hr]	Fresh air rate [1/hr]	Heat recovery efficiency [%]
VNT_SHP_FRA_V	Ventilation rate in shops	0.6	0	0.6	60
VNT_FDS_FRA_V	Ventilation rate in the food store	2	1.4	0.6	-
VNT_MDS_FRA_V	Ventilation rate in midsize store	4	3	1	-
VNT_CMA_FRA_V	Ventilation rate in common areas	2.5	2	0.5	-
VNT_WRH_FRA_V	Ventilation rate in warehouse	0.5	-	0.5	-
VNT_OFF_FRA_V	Ventilation rate in office	2	-	2	-

Occupancy

The internal gain due to the presence of persons has been quantified by considering a specific density of 0.25 person/m² in the shops and the food store, 0.20 person/m² in the medium store the offices and the common areas and 0.10 person/m² in the warehouse zones. These values are also confirmed by the data registered by people counters installed in the shopping malls.
The EN ISO 7730 standard recommends to consider a total heat flux of 185 W/person for retail store case where people are standing and performing light work. This value takes into account sensible (90 W/person) and latent gains (95 W/person).

Occupancy profiles are derived from popular times shown in Google search[7]. The daily occupancy

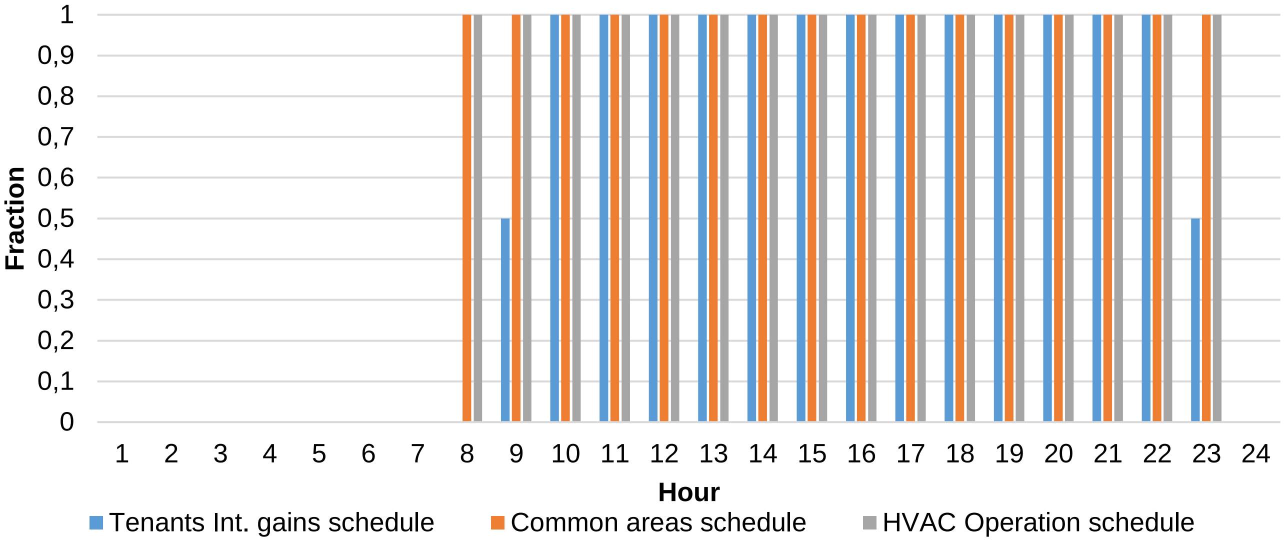


Figure 129. These schedules are applied to every weekday and weekend day over the year except for closing days, which are January 1st, May 1st and December 25th.

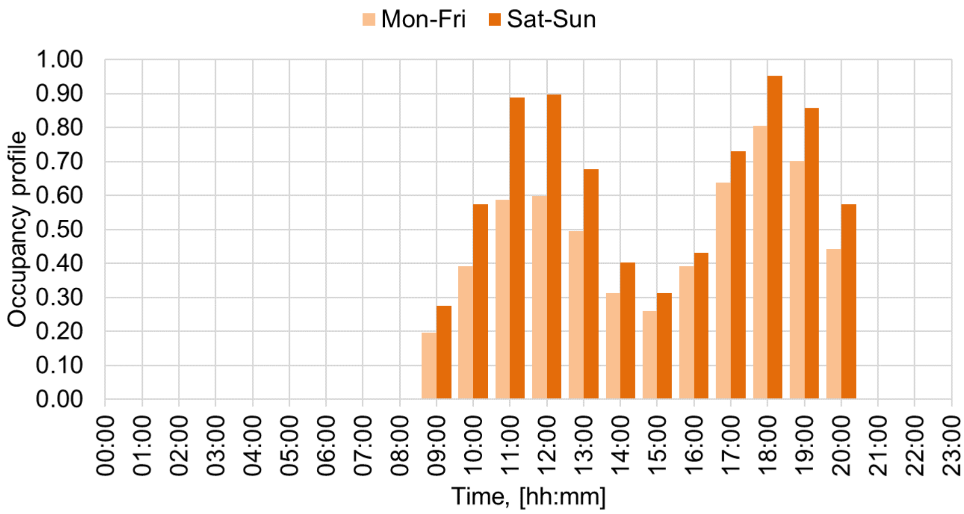


Figure 175. Occupancy profile during weekdays and weekends.

Lighting

Lighting gains have been set according to the information provided by IGD after a visit to the shopping centre (Figure 176 and Figure 177). We set a specific internal gain for lighting of 80 W/m² in the shop zones, 50 W/m² in the medium store, 25 W/m² in the food store, 20 W/m² in the common areas, 20 W/m²

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[7] Google Search shows users the most popular times for some of their favorite businesses and institutions. When users search for places like a restaurant, bar, or gym on Google, they'll see when their destination typically draws the largest crowds. To determine popular times, Google uses data from users who have chosen to store their location information on Google servers. Popular times are based on average popularity over the last several weeks. Not all businesses will have a popular times graph; the graph will only appear for businesses whose hours are listed on Google and about which Google has sufficient popularity data. On the popular times graph, popularity for any given hour is shown relative to the typical peak popularity for the business for the week.

in offices, 15 W/m² in the warehouses and 2.2 W/m² in the parking zone. This value has been divided between 0.6 convective and 0.4 radiative fractions.

Figure 176. Stairwell shaft luminaries.

Figure 177. Shop gallery luminaries.

The daily lighting operation schedule for the each zone typology is reported in Figure 178. Common areas are day-lighted, therefore lighting power is reduced to 30% during daytime.

Figure 178. Lighting schedules.

Other electric equipment

We set a specific internal gain for electric equipment of 10 W/m^2 in shops, medium store and offices, 5 W/m^2 in the food store. As shown in the graph in Figure 179, loads are on only during occupied hours. According to the information provided by IGD, refrigeration cabinets in the food store dissipate around 70000 frig/h and therefore internal gains due to refrigeration cabinets are set to -81395 W (-10 W/m^2). Electric equipment power is reduced to 10% during closing time and holidays (January 1st, May 1st, December 25th).

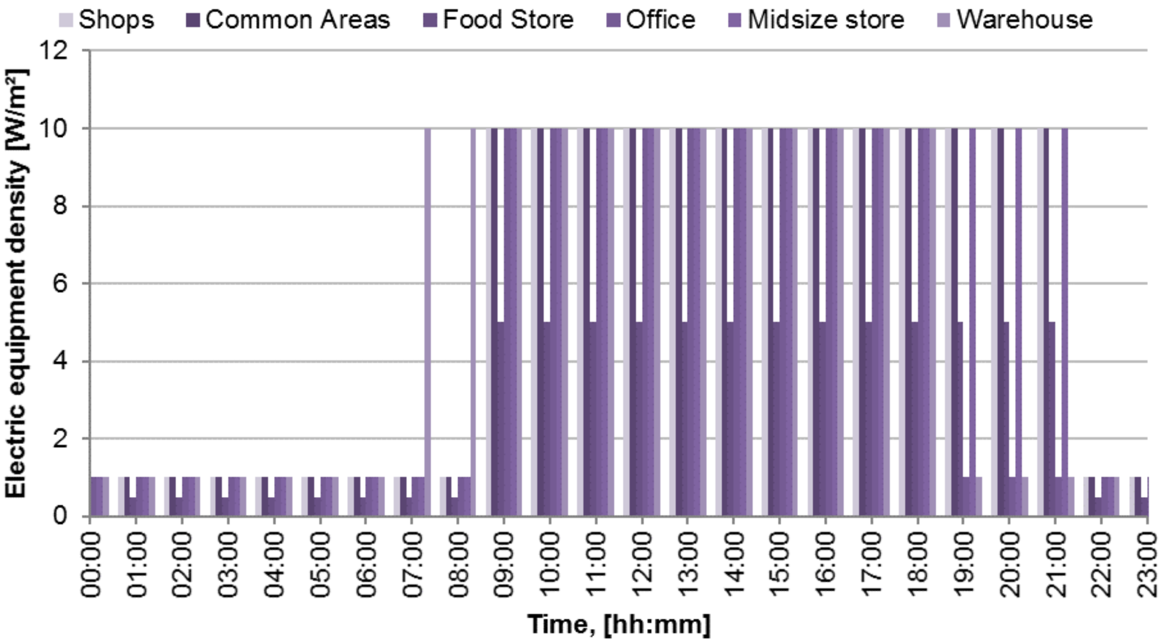


Figure 179. Other electric equipment schedules.

HVAC system

The common areas are conditioned with three rooftop air conditioning units with a COP of 2.71. This value is reduced by 87% taking into account control, distribution and emission losses. The units recover part of the exhaust air and mix it with outdoor air: on average 70% of the supplied air is recirculated air and 30% is outdoor fresh air. An air extractor balances the mass flow. The system works at constant airflow rate during the opening hours and it is attenuated overnight. Full recirculation mode is set in the first opening hours until the set-point indoor temperature is reached. The airflow is regulated by thermostats, but there is no external temperature sensor.

The midsize shops are conditioned by means of a rooftop air conditioning unit each. No information are available regarding the units’ regulation mode. Table 32 reports the rooftop features.

Table 32. Rooftop (RT) air conditioning units features.

ID	Description	Supply flow rate [m^3/hr]	Supply - Pressure drop [Pa]	Recirculated flow rate [m^3/hr]	Extract flow rate [m^3/hr]	Extract - Pressure drop [Pa]	Cooling capacity [kW]	Heating capacity [kW]
RT1_GALL.	south gallery	36840	550	29840	7000	550	213.5	139.5

RT1_GALL. PT	north gallery at +6.88m	21000	650	15000	6000	650	139.5	91
RT2_GALL.	central gallery	36840	550	29840	7000	550	213.5	139.5
RT3_GALL.	north gallery at +12.29m	36230	550	30230	6000	550	220	132
RT1_MSA	shop A	6600	350	5000	1600	250	41.5	27
RT1_MSB	shop B	6900	350	4400	2500	250	51.5	35.5
RT1_MSC	shop C	11900	400	8930	2970	300	75.5	49.5
RT1_MSD	shop D	19600	400	14700	4900	350	125	81.5
RT1_MSE	shop E	8600	400	5140	3460	350	48.5	31.5
RT1_MSF	shop F	14000	400	10150	3850	350	92	60
RT1_MSG	shop G	14000	400	10150	3850	350	92	60
RT1_MSGS2	shop GS2	26500	450	19025	7475	400	175.5	114.5
RT2_MSGS2	shop GS2	26500	450	19025	7475	400	175.5	114.5

Three air handling units with heat recovery provide air changes to the shops (Table 33) and fan coils served by two air to air heat pumps are conditioning the spaces. No information on heat recovery efficiency is available. We assumed therefore a 60% heat recovery efficiency.
The technical specification on the heat pumps are:

- Cooling power = 750 kW
- Power absorbed in cooling mode = 250 kW
- Heating power = 820 kW
- Power absorbed in heating mode = 240 kW

Table 33. Features of the Air Handling Units (AHU) that condition the shops.

ID	Description	Supply flow rate [m^3/hr]	Supply - Pressure drop [Pa]	Extract flow rate [m^3/hr]	Extract - Pressure drop [Pa]
AHU 1.	North shops	23790	520	23790	509
AHU 2	West shops	21610	400	21610	400
AHU 3	South shops	12020	380	12020	400

Therefore, we considered the following efficiencies to estimate the electricity consumption due to the shops' air conditioning:

EER = 3.6

COP = 4

The difference between outdoor temperature and temperature set-points is also taken into account in the hourly estimation of heating and cooling electricity consumption.

Considering a constant flow rate during the opening hours, we derived the air changes from the conditioning and air handling units' airflow and the zone volumes. Table 34 reports the average values which have been set to simplify simulations' inputs. A ventilation setback lowers ventilation rates by 70% during non-occupied time.

Table 34. AHU and RT airflow rates and specific fan power.

Zone function	Supplied airflow [1/hr]	Recirculated airflow [1/hr]	Fresh airflow [1/hr]	Specific fan power [Wh/m³]
Common areas	2.5	2	0.5	0.60
Midsize stores	4	3	1	0.45
Shops	-	-	0.6	0.45

No information about the HVAC and refrigeration plant layout of the hypermarket are available, neither the energy consumption due to refrigeration is measured.

A specific fan power of 0.65 Wh/m³ in shops and common areas, 0.45 Wh/m³ in midsize stores and 0.75 Wh/m³ in the food store is considered to estimate the electricity consumption of ventilation.

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

Model calibration

The model is calibrated on the basis of monthly and hourly electricity consumption of common areas (external lighting of parking lots and shops AHU is also included) in 2014. Since no monitored data are available from tenants, the shops and food store zone model cannot be calibrated. The model calibration has been performed using the weather file provided by Weather Analytics (Weather analytics, 2015) representing the actual meteorological year (AMY) of 2014 in Catania.

The model has been manually calibrated by observing the average daily electric power profiles during winter (Figure 180) and summer (Figure 181) derived from monitored data.

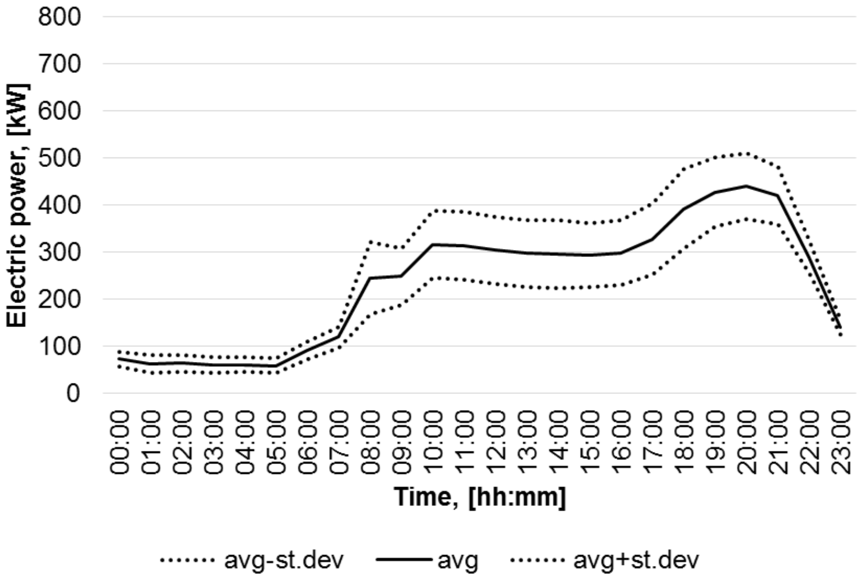


Figure 180. Average daily electric power profiles during winter.

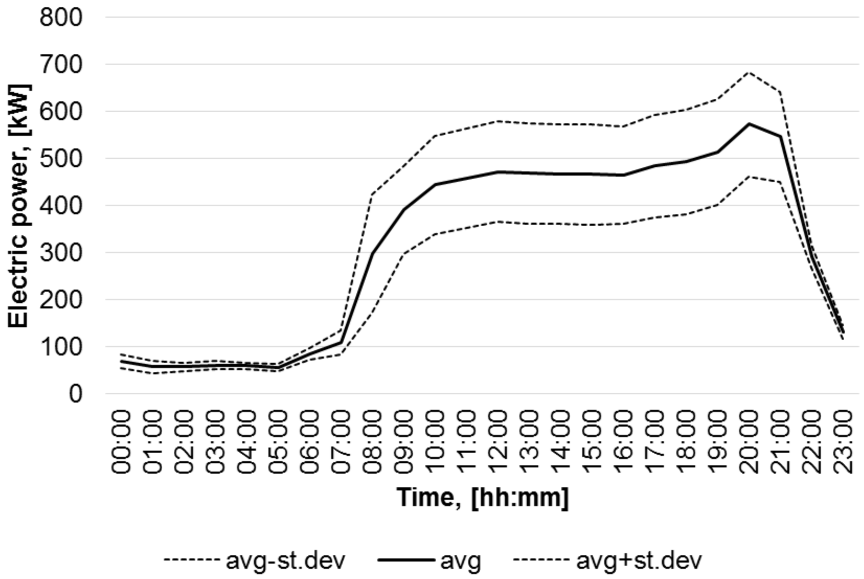


Figure 181. Average daily electric power profiles during summer.

Observing the average profiles, it can be noticed that the peak power occurs on 6pm -9pm during winter and on 8pm – 9pm during summer. After a conversation with the energy manager we confirmed that the peak power is due to the additional lighting that are turned on at evening.

Therefore, we modified the lighting schedule introducing a peak from 7pm to 9pm. The lighting schedule should depend on sunset time during each season, but we kept the same schedule for the whole year to avoid model complexity.

We also increased the internal gains in common areas at evening to take into account of the restaurant area presence in the main atria.

Heating and cooling schedules have also been adjusted to better fit the average electric power profile coming out from monitored data. Heat recovery efficiency has been increased from 40% to 60%.

A new equation was introduced to calculate the infiltration rates taking into account of indoor – outdoor temperature differences, instead of setting constant infiltration rates.

Figure 182 and Figure 183 show the average daily profile of electric power, in winter and summer respectively, resulting from simulation compared to the data measured in 2014.

The unlimited power assumption also causes a higher peak power during the first opening hours, which is not coherent with the measured data. These input data also causes the underestimation of cooling demand during the summer and the overestimation of heating demand during the winter period. The introduction of the recirculation mode during the first opening hours reduced significantly the peak power demand.

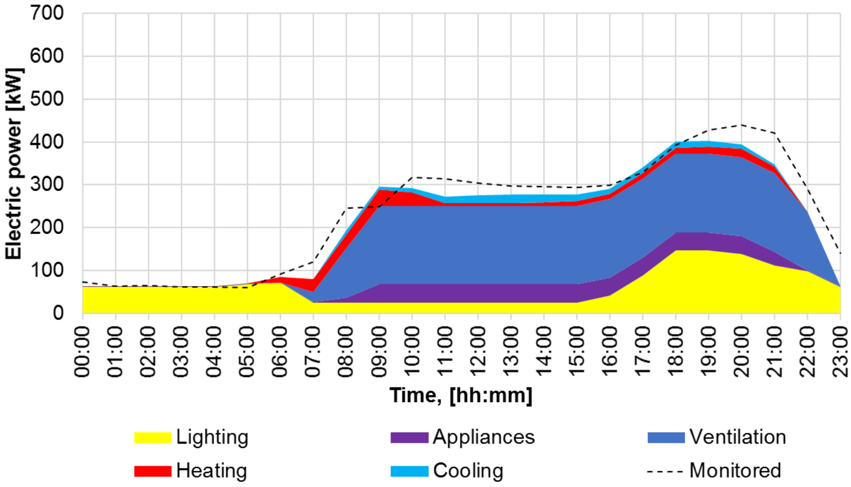


Figure 182. Average daily profile of electricity consumption of common areas in winter from simulation results compared to the data measured in 2014.

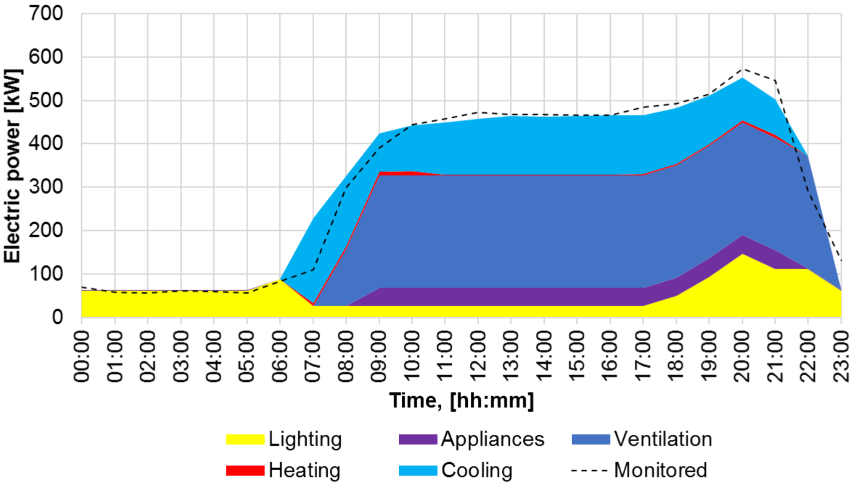


Figure 183. Average daily profile of electricity consumption of common areas in summer from simulation results compared to the data measured in 2014.

According to the monitored data, the total electricity consumption of the common areas in 2014 amounts at 2433 MWh. The calibrated model predicts a total electricity consumption of 2914 MWh.

Baseline model outcomes

This paragraph reports and analyses the baseline model outputs. The simulations here are run with the weather file generated by Meteonorm (Meteotest, 2015) and representing the typical meteorological year (TMY) of Catania.

Energy balance

The graph in Figure 184 and Figure 185 represent the monthly and weekly specific energy balance over the whole building. The total heating demand is around 50 kWh/m²-y, whereas cooling demand is aorund 150 kWh/m²-y.

Cooling season starts from week 18 (May) and ends in week 43 (October), even though some cooling need can occur during winter season mailny in the shops because of their high lighting power density. Internal gains are dominant among the positive items of the energy balance. Ventilation losses contribute positively to free cool the building during middle seasons (week 18-24 and week 36-43), but cause an increas of cooling need during July and August (week 25-35).

Thermal losses due to infiltration rates are significant in winter time and a reduction of infiltration rates through a better control of door opening or envelope air tightness improvement can potentially reduce heating demand.

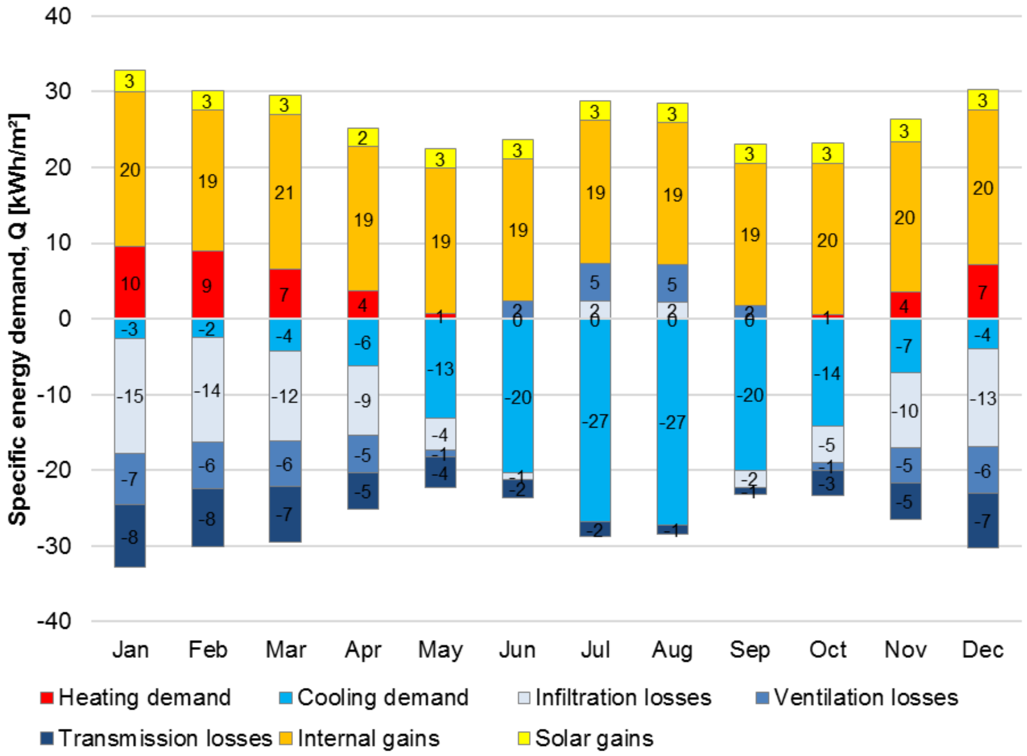


Figure 184. Monthly energy balance – whole building.

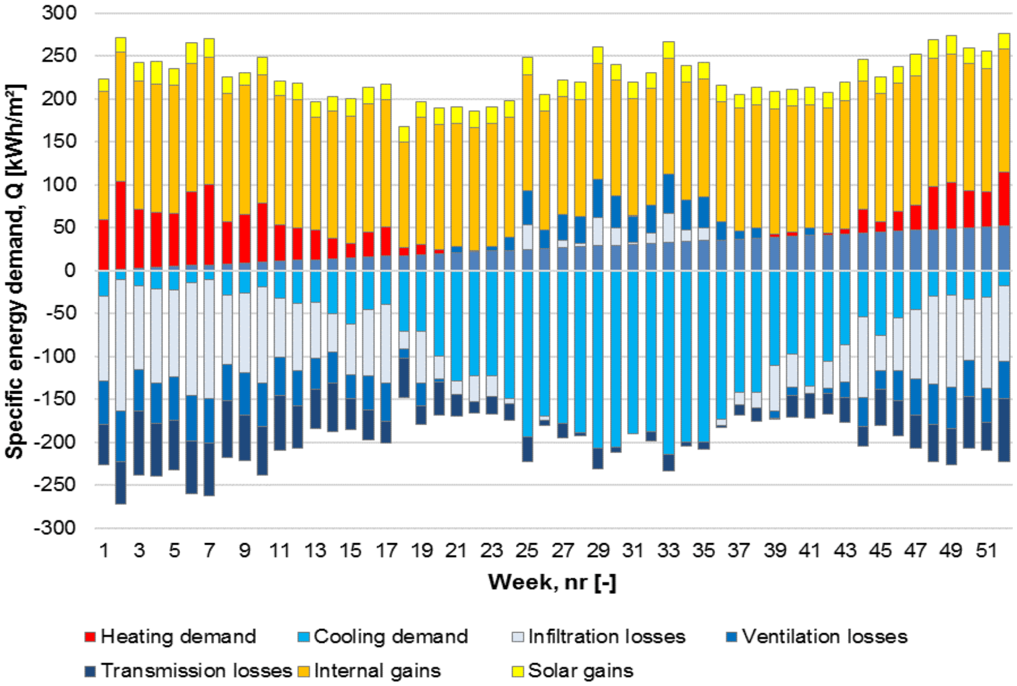


Figure 185. Weekly energy balance – whole building.

The graph in Figure 186 represent the specific energy balance of each model zone. Observing the graph, it can be noticed that heating demand is significant in common areas only due to the lower internal gains level compared to the shops.

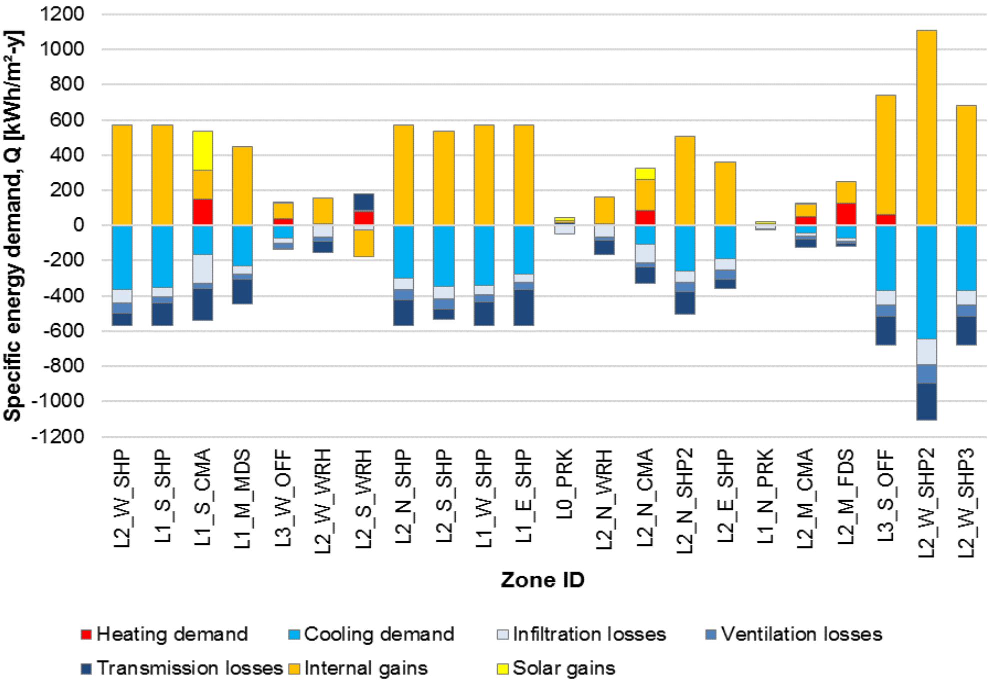


Figure 186. Energy balance of each model zone.

Electricity consumption

The graph in Figure 187 represents the electricity consumption divided by zone function. The shop zones (SHP) have the highest electricity consumption due to the high lighting power density.

According to our model predictions, the most affecting energy use are due to HVAC systems (45% of the total electricity consumption), followed by lighting (39%), refrigeration (9%) and other electric equipment (7%).

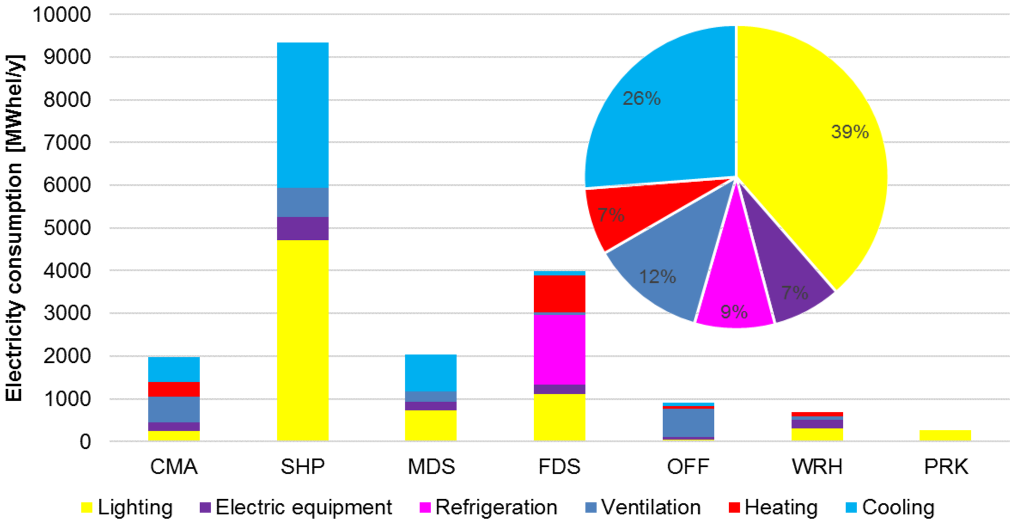


Figure 187. Electricity consumption for each group of zones.

Total electricity consumption amounts at 19222 MWh which corresponds to 698 kWh/m²-y considering the conditioned area of 32044 m².

With a primary energy factor of 2.046 kWh_{pe}/kWh_{el}, the total primary energy consumption amounts at 1429 kWh_{pe}/m^2y.

Considering the carbon factor as 0.521 kg_{CO_2eq}/ kWh_{el}, the carbon emissions of the shopping centre amount to 10015 $tons_{CO_2eq}$ per year.

IGD is responsible for the facility management of the common areas. Shops and food stores are leased by IGD and managed by the respective tenant. Lease agreement lasts generally 5 year. Tenants contract for electricity services and IGD does not have access to their electricity consumption because of privacy reasons. Tenants pay a fixed percentage of the shopping centre's utility bill and maintenance for parking and common areas and for shops air conditioning based on the square footage.

Since the solution set is addressed to IGD, it is worth to break down the energy consumption data for common areas (Figure 188). The air conditioning and ventilation accounts for over ¾ of the total energy consumption. Internal and external lighting as well as plug loads accounts for almost the same amount of energy.

The overall electricity consumption for common areas is estimated at 2915 MWh which results in monthly average operational expenses of around 36000 €, considering an electricity price of 0.15 €/kWh. Tenants pay a fixed percentage of the shopping centre's utility bill and maintenance for parking and common areas and for shops air conditioning based on the square footage.

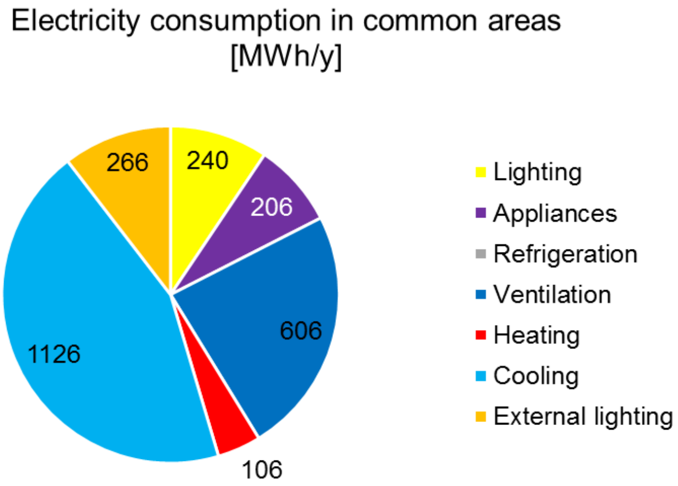


Figure 188. Electricity consumption breakdown for common areas.

Solution set

The solution set here described is balanced on the specific needs of the Katane' reference building and the climate conditions of Catania. Therefore, its replication in other climates or other buildings need to be further investigated.

Since shops and food store are leased by IGD and each tenant manages their shop on their own, we focused the solution set on common areas only. **Considering that Katane is quite a new shopping centre (built in 2009), there is no plan for restyling and therefore the proposed solution set mainly focuses on the management of the existing features and component in the most efficient way. Solutions with low investment costs (i.e. HVAC controls, natural ventilation) or with low pay back time (i.e. lamps replacement – 13 months PBT) are preferred instead of solutions requiring a shopping mall restyling (i.e. envelope insulation).** Considering the fact that lighting is responsible for most of the electricity consumption of the mall, we first decide to reduce lighting power density (**solution 1**) by installing more **efficient and dimmerizable lighting systems**. Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need by around 19%, but increasing the heating demand by around 36%.

Assuming that costumers can adapt to slightly higher indoor temperatures in summertime and lower indoor temperatures in winter time, we set **more relaxed comfort temperature ranges**, (**solution 2**).

In order to reduce the energy consumption due to ventilation, we implemented **demand control ventilation** on each of the 3 air handling units (**solution 3**). The amount of outdoor ventilation is adjusted depending on the inflow of people and/or the level of CO_2.

The lower cooling need allows for the exploitation of **natural ventilation** within common areas (**solution 4**). Existing openings, designed for smoke ventilation can also help vent out stale air in the hot days.

The connection of opening control to the iBEMS would allow to switch off the mechanical ventilation and cooling in the common areas when natural ventilation is activated and to introduce a more sophisticated control strategy.

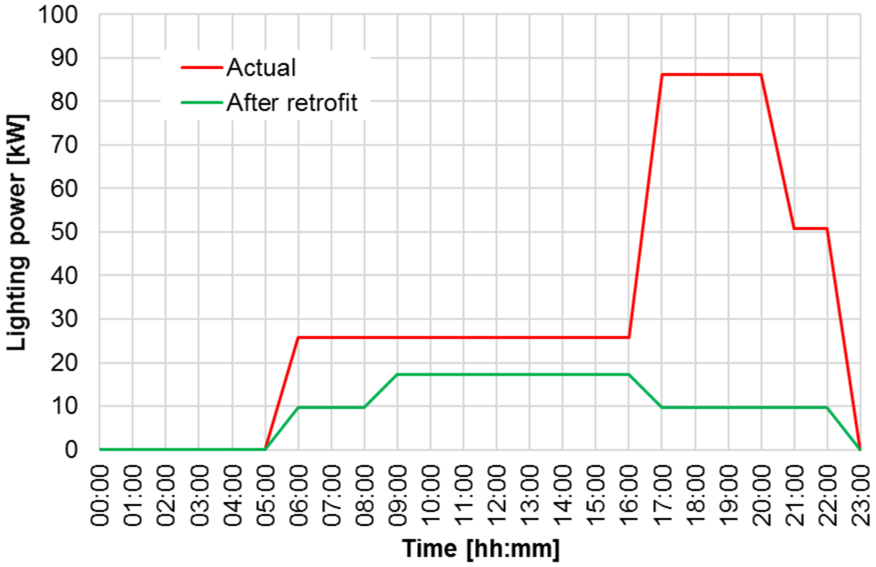
Finally, the installation of **PV plant** on the gallery roof and on parking canopy on the roof (**solution 5**), for a total of 580 kWp, will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. The expected electricity production amounts at circa 888 MWh/y. Furthermore, the canopy shade will decrease the cooling need on the roof.

Solution 1: Efficient lighting system and controls

Objective	To reduce internal gains and lighting consumption by installing more efficient and dimmerizable lighting systems

Description

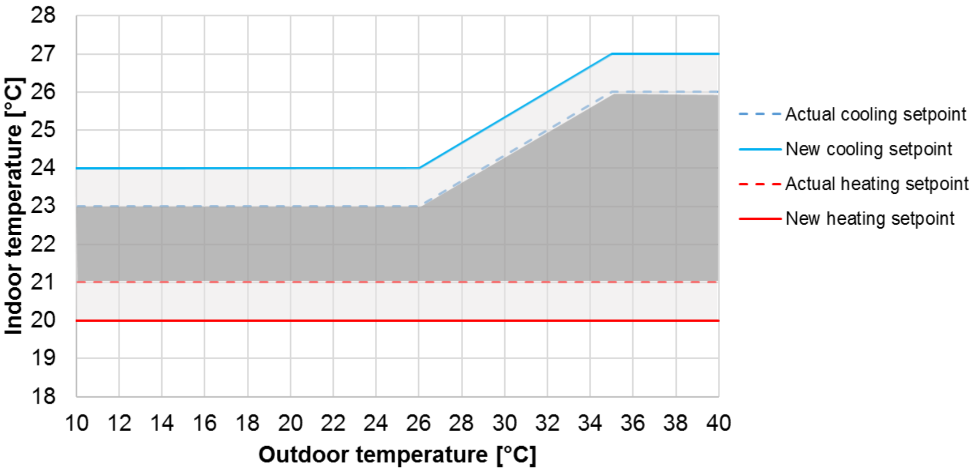
Lighting power density is reduced down to 4.5 W/m² in the common areas because of the installation of LED lamps.
Zonal lighting concept reduces ambient lighting, accentuates zones with higher intensity and maintains the perceived brightness impression.
Advanced controls on light colour and dimmerizable lights allow to reduce lighting intensity during night milieu, after sunrise during opening time.



Area of application	Common areas: atria and gallery
Expected energy savings	31% reduction of lighting electricity consumption 19% cooling need reduction 36% heating need increase
Expected impact on IEQ	Glare is reduced and we manage to bring the indoor lighting condition closer to outside natural situation (warm-white colour in the evening). Therefore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall. Lighting levels in the shops can be lower keeping a stable visual comfort and perception since the lighting levels in the shops are harmonized with the ones in the common areas.
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have a bigger impact on overall building energy consumption.
Expected investment costs	The estimated cost for lamps replacement is 14 €/m². Considering the area interested, an investment of 95'544€ is needed.

Solution 2: Heating and cooling setpoint management

Objective	to reduce heating and cooling consumption by applying advanced controls on temperature setpoints
Description	Assuming that costumers can adapt to slightly higher indoor temperatures in summertime and lower indoor temperatures in winter time, we set more relaxed comfort temperature ranges. Heating setpoint is lowered by 1K (from 21°C to 20°C) and cooling setpoint varies between 24°C and 27°C depending on outdoor temperature.

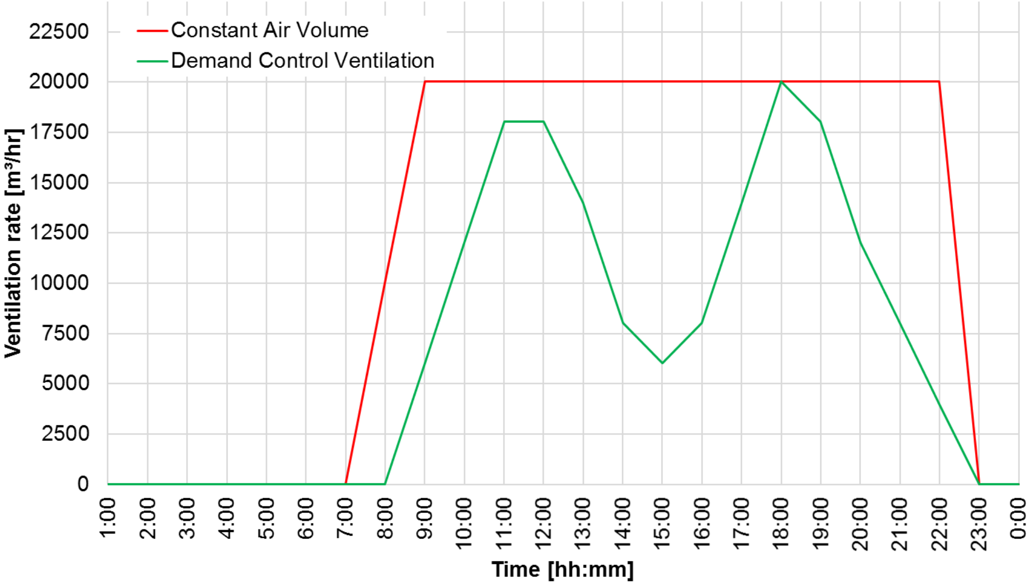


Area of application	Common areas: atria and gallery
Expected energy savings	Energy consumption for common areas air conditioning is expected to decrease by 20%.
Expected impact on IEQ	Impact on thermal comfort can be monitored by means of measurement and interviews campaigns.
Interaction with other solutions	This setpoint adjustment needs to be extended to the whole shopping center in order to avoid unbalances between shops and common areas.
Expected investment costs	No additional equipment is needed for this solution since it is implemented by just changing a BMS setting.

Solution 3: Demand control ventilation (DCV)

Objective to reduce energy consumption for ventilation by controlling airflows depending on CO2 levels

Description The amount of outdoor ventilation is adjusted depending on the inflow of people and/or the level of CO_2. Therefore, fresh air is provided only when it is needed, i.e. higher inflow times (between 11am and 13 am, between 17pm and 20pm).



Area of application Common areas

Expected energy savings Up to 53% less energy consumption for ventilation

Expected impact on IEQ Even though the amount of outdoor ventilation might be lower than baseline solution, no impact of indoor air quality is expected because air changes are delivered just when they are needed.

Interaction with other solutions The lower ventilation rates have an impact on heating and cooling need which is further reduced by around 7%.

Expected investment costs The cost of implementation depend on the existing HVAC system. If the system already has a modulating outdoor air damper with digital control, then the retrofit may be simple and cheap. In this study we assumed the worst case scenario where the 4 rooftop units which ventilate the common areas and the 3 AHU which ventilate the shops do not have modulation options and therefore inverters need to be added. We considered 6000-7000 € per inverter.

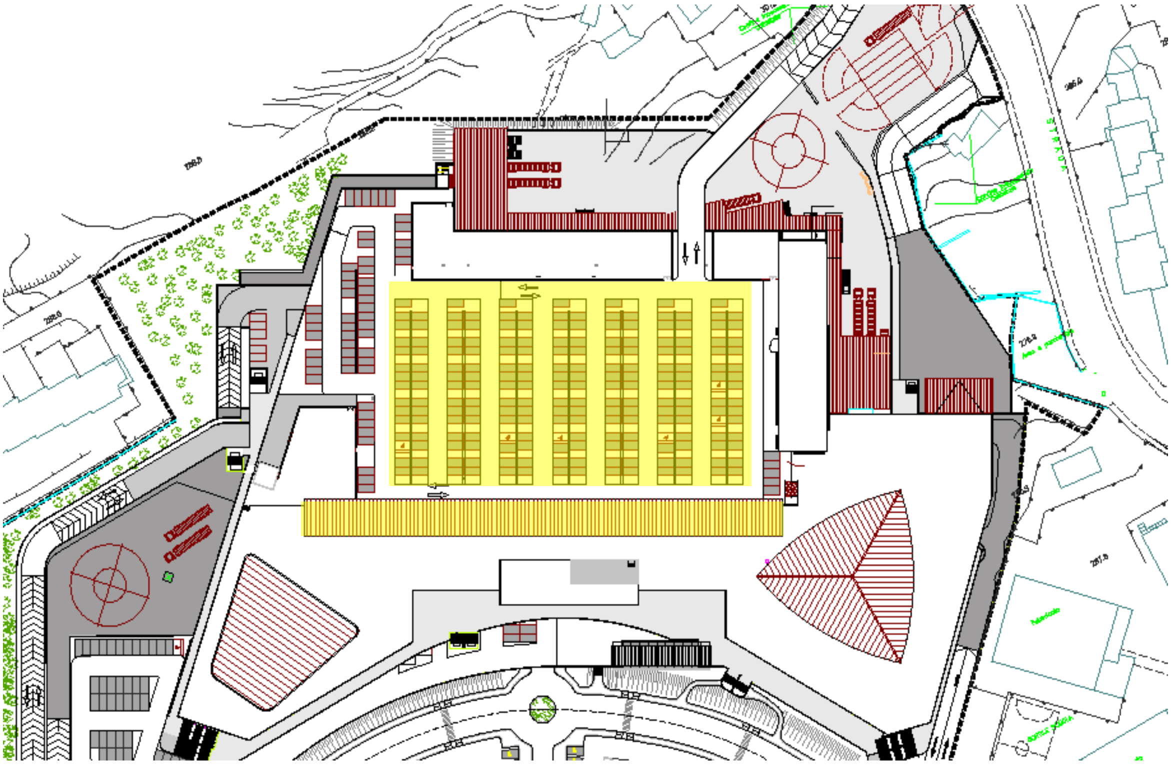
Solution 4: Natural ventilation

Objective	To reduce energy consumption for ventilation and cooling need by exploiting existing automated openings to enhance stack natural ventilation in common areas
Description	Natural ventilation through openable windows in the atria and gallery skylights help vent out stale air in the summer. Combining the effect of opened sliding doors and skylight openings can enhance stack ventilation and ventilate/cool the common areas. The connection of opening control to the iBEMS and the integration of inverters automated by the iBEMS would allow to switch off the mechanical ventilation and cooling in the common areas when natural ventilation is activated and to introduce a more sophisticated control strategy.

Area of application	Common areas
Expected energy savings	Cooling demand reduction by 1% in the common areas Electricity consumption due to ventilation of the common areas reduced by 13%
Expected impact on comfort	Increasing the air velocity within the indoor environment improves the comfort sensation of customers at high indoor temperatures. During shoulder season, natural ventilation provides higher ventilation rates than demand control ventilation ensuring a higher IAQ.
Interaction with other solutions	The reduction of cooling demand thanks to the efficient lighting systems and increase the potential of ventilative cooling
Expected investment costs	According to our preliminary cost estimation, we assumed a total investment of around 37’141 € which includes motors for 81 windows, controller units, weather station and indoor air temperature sensors, as well as installation costs. Cost could be lower if the existing window motors can be programmed and connected to the existing BMS.

Solution 5: PV plant on gallery roof and parking canopies

Objective	to decrease the energy imported from the grid and the CO2 emissions by generating and self-consuming renewable energy
Description	208 kWp PV plant is installed on the roof gallery and another PV plant of 372 kWp is installed on new parking canopies on the roof.



Area of application	Roof gallery and parking canopies on roof parking lots.
Expected energy savings	The PV plant is expected to produce 888 MWh/y of electricity. The yearly simulation performed using consumption data from common areas with energy conservation and efficiency measures gave the results of around 40% of self-production, 60% of self-consumption.
Expected impact on comfort	The PV installation will create shaded parking lots, which are preferred from customers especially during the summer period. Lower ceiling surface temperature improves thermal comfort, especially in the offices on the roof
Interaction with other solutions	PV plant is sized according to the load peaks estimated after the implementation of all the energy conservation and energy efficiency measures.
Expected investment costs	Costs for PV plant (installation included) on commercial buildings is around 1600 €/kWp. The cost of PV plant on parking canopies (parking canopy included) is estimated at around 2800 €/kWp. Maintenance costs are considered to be 20 €/kWp/year, excluding the first 2 years since generally PV plant are still under guarantee.

Energy performance of the solution set

This chapter reports the expected energy savings of the solution set and compared to the actual building energy consumption predicted by the simulation model.

Potential energy savings

The graph in Figure 189 shows the actual yearly final energy consumption of the common areas in the baseline model and the potential energy savings of the energy efficiency measures described in the previous sections.

The solution set package analysed leads to a reduction of 58% of electricity consumption. Up to 40% of energy savings can be achieved by just optimizing heating, cooling and ventilation controls. Thanks to the PV plant we can have up to 40% of self-production and 60% of self-consumption.

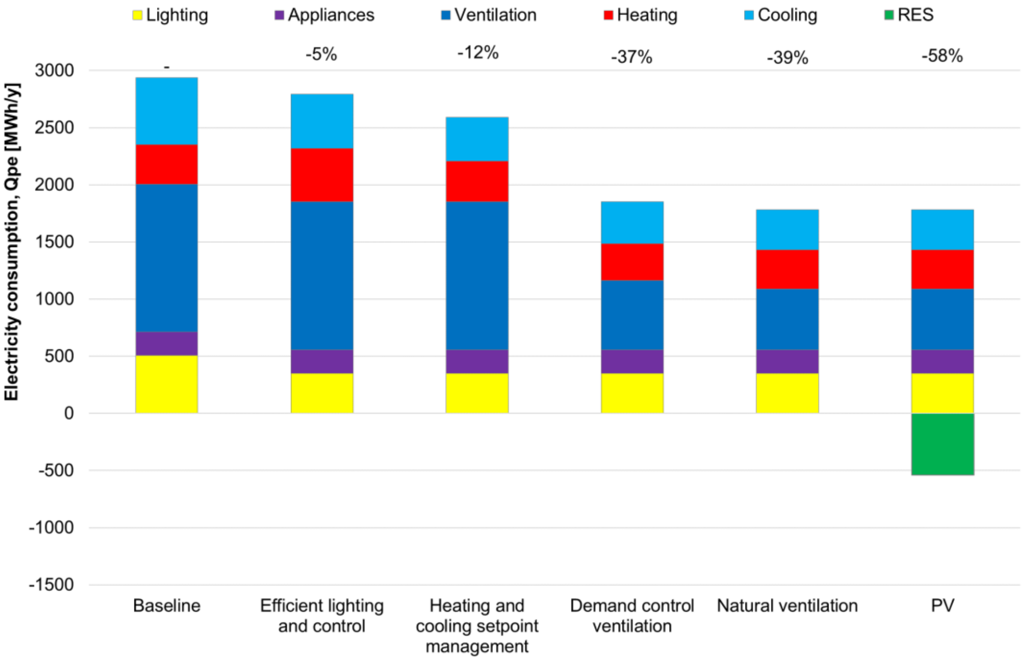


Figure 189. Yearly final energy consumption of the common areas.

Primary energy reduction

The graph in Figure 190 shows the actual yearly primary energy consumption of the common areas in the baseline model and the potential primary energy savings of the energy efficiency measures, considering a primary energy factor of 2.046 kWh_{pe}/kWh_{el}.

Since the systems are all electric, the percentages of primary energy reduction referred to the baseline are the same as the one estimated for the electric energy savings.

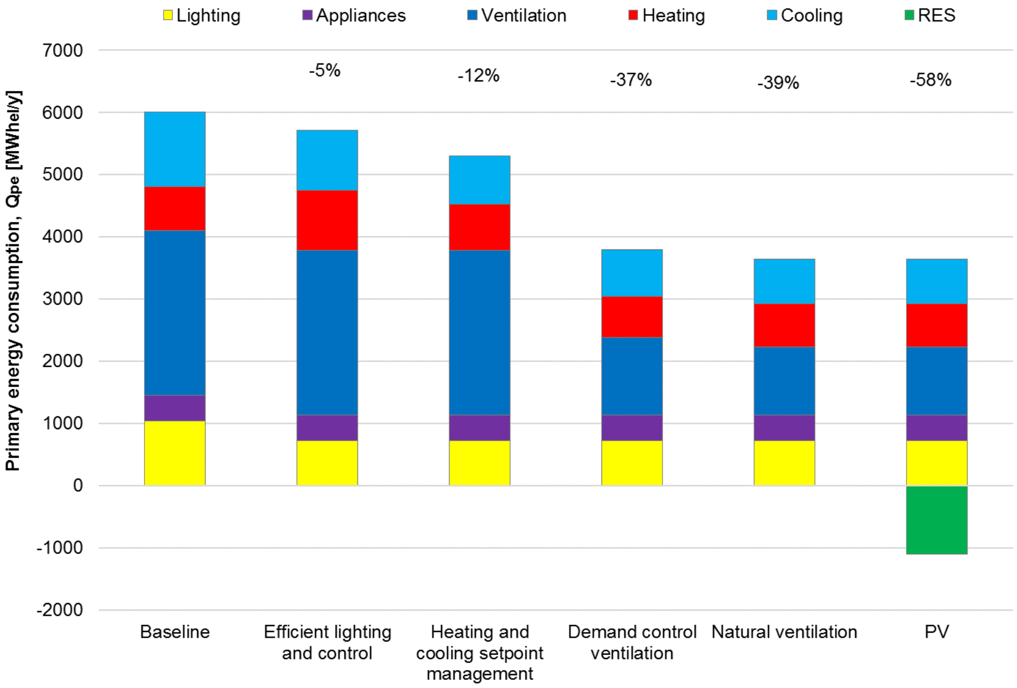


Figure 190. Yearly primary energy consumption of the common areas.

Economic analysis

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 2 million €, most of which is due to the PV plant. The total cost of investment of energy conservation and efficiency measures only is estimated at around 208,000 € (incl. tax).

Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 174,000 €/year and the revenues due to the sale of electricity to the grid from the PV plant are estimated as 121,900 €/year.

Table 35. Assumptions on cost of investment of the solution set.

Equipment	Cost
Efficient and dimmerizable lamps	60,242 €
Weather station	2,000 €
Indoor temperature sensors in galleries	420 €
Inverters on 4 rooftop units	42,000 €
Window actuators and control units	26,150 €
PV plant (installation included)	1,374,400 €
Installation costs (20% of the equipment costs)	26,162 €
Engineers and permitting (10%of the equipment costs)	105,521 €
Total	**1,681,896 €**
Tax (31.4%)	370,017 €
Total cost of investment (incl. tax)	**2,051,913 €**

The economic analysis is based on the assumptions reported in Table 36.

Table 36. Economic analysis assumptions

Assumptions	Value
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	0-8%
Energy costs	
Cost of electricity	0,15 €/kWh
Electricity buy price annual variation	1,0%/year
Electricity sell price annual variation	1,0%/year
Installation ageing	0,5%/year
Operation costs	
Insurance	0,5%
Taxes	1,0%
Maintenance	1,5%
Miscelaneous supplies	0,2%
Contingency	10% from previous concepts
Annual variation	0,5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**.

The results of the cash inflows and outflows for the whole solution set are shown over the 25 years period studied are shown in the graphs in Figure 191 and Figure 192.

The estimated Pay Back Time is expected to be between **5.1 (discount factor 0%) and 6.8 years (discount factor 8%)** depending on the discount factor which can be applied to the investment.

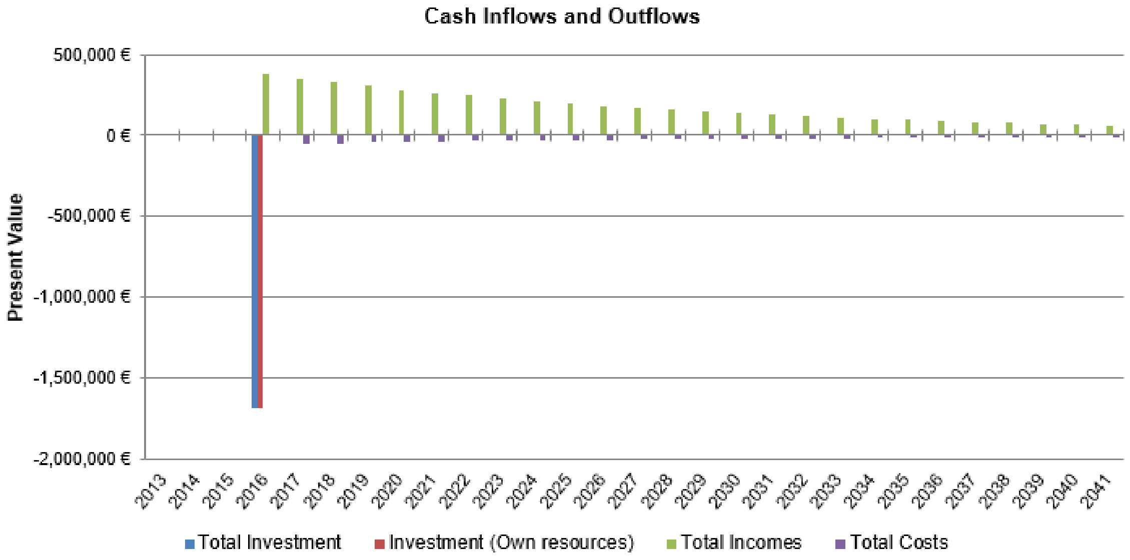


Figure 191. Cash inflows and outflows.

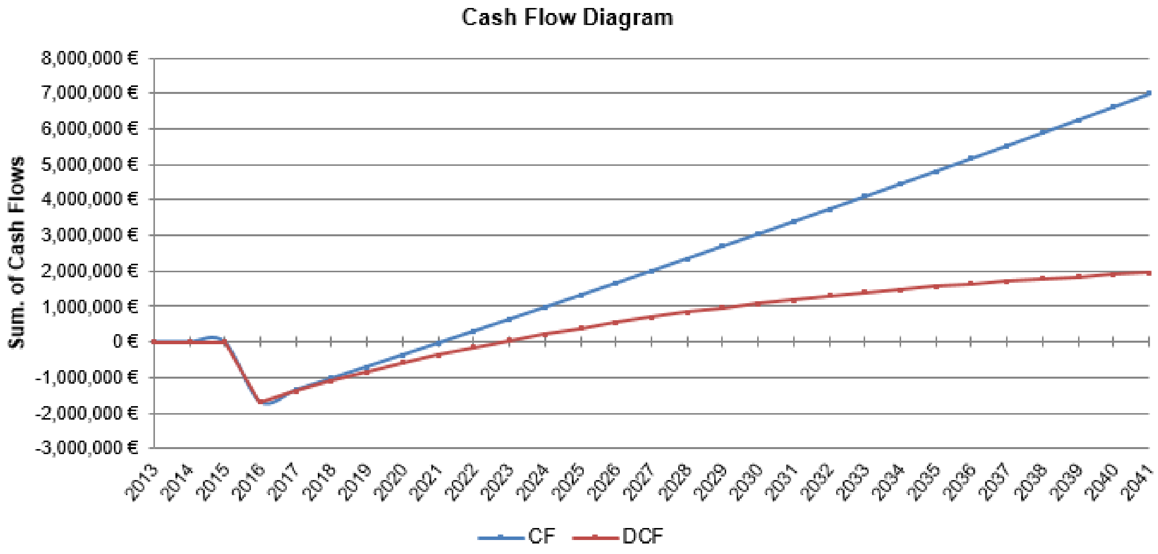


Figure 192. Cash flow diagram.

Table 37 reports partial results of the economic analysis performed by progressively stacking energy conservation and energy efficiency measures.

The Pay Back Time of energy conservation and efficiency measures only can be lower than 2 years.

Table 37. Economic analysis on stacked measures.

Solution		Investment individual solution [€]	Total investment [€]	Operation cost savings [€/year]	Revenues [€/year]	Energy savings [kWh/year]	Energy savings [%]	ROI [%]	Pay Back Time [years]	Net Present Value [€]	Discounted Pay Back Time [years]	Discounted Net Present Value [€]
1	Efficient and dimmerizable lighting systems	95’544	95’544	21’560	-	143’733	5	21	4.83	347,860	6.34	100’260
+2	Heating and cooling setpoint management	-	95’544	51’988	-	346’583	12	60	1.67	1’163’584	1.87	442’102
+3	Demand control ventilation	51’240	162’156	162’708	-	1’084’720	37	100	<1	3’971’362	<1	1’587’011
+4	Natural ventilation	37’141	207’468	173’723	-	1’158’155	39	96	1.04	4‘157‘517	1.14	1’643’436
+5	PV plant	1’374’400	2’051’913	254’735	121’900	1’698’232	58	19	5.10	6’988’668	6.79	1‘951’075

Conclusions

Considering that Katane' is quite a new shopping centre (built in 2009), there is no plan for restyling and therefore the proposed solution set mainly focuses on the management of the existing features and component in the most efficient way. Solutions with low investment costs (i.e. HVAC controls, natural ventilation) or with low pay back time (i.e. lamps replacement – 13 months PBT) are preferred instead of solutions requiring a shopping mall restyling (i.e. envelope insulation).

Since shops and food store are leased by IGD and each tenant manages their shop on their own, the study is focused on common areas only.

The solution set proposed includes:

- Solution 1: efficient and dimmerizable lighting systems
- Solution 2: heating and cooling setpoint management
- Solution 3: demand control ventilation
- Solution 4: natural ventilation
- Solution 5: RES production from PV plant

The solution set package analysed leads to a reduction of 58% of electricity consumption. Up to 40% of energy savings can be achieved by just optimizing heating, cooling and ventilation controls. Thanks to the PV plant we can have up to 40% of self-production and 60% of self-consumption.

Considering the expected investment costs related to each solution, we planned a total cost of investment of around 2 million €, most of which is due to the PV plant. The total cost of investment of energy conservation and efficiency measures only is estimated at around 208'000 € (incl. tax).

Considering an average cost of electricity of 0.15 €/kWh, the energy savings due to energy conservation and efficiency measures are expected to be around 174'000 €/year and the revenues due to the sale of electricity to the grid from the PV plant are estimated as 121'900 €/year.

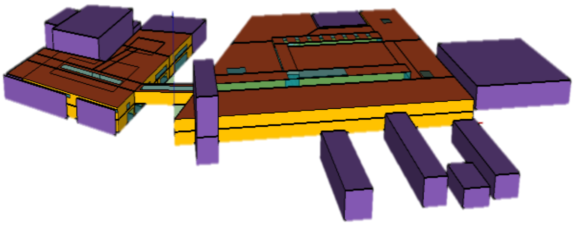
The estimated Pay Back Time is expected to be between **5.1 (discount factor 0%) and 6.8 years (discount factor 8%)** depending on the discount factor which can be applied to the investment. The Pay Back Time of energy conservation and efficiency measures only can be lower than 2 years.

Donauzentrum (Wien - Austria)

Building model: input data summary

General data	
Building footprint [m²]	58145
Gross Leasable Area [m²]	81364
Food store vending area [m²]	8131
Tenants vending area [m²]	73233
Common areas and galleries [m²]	11257
Number of opening hours per day [h/d]	11
Number of opening days per week [d/w]	9
Number of closing days per year [d/y]	10

Thermal zone model



Number of thermal zones	35
First floor height [m]	5.1
Second floor height [m]	5.1
Zone typology	Zone group area [m²]
Shops	37543
Medium size store	2993
Food store	8131
Restaurants	1196

Building envelope BT 1-3,4-5,9		
Opaque envelope components	U-value [W/m²K]	Solar absorptance [-]
Exterior walls	1.378	0.6
Adjacent walls	2.088	0.6
Exterior roof	0.295	0.6
Ceiling/interior floors	0.353	0.6
Ground floor	0.798	0.6

Building envelope BT 7		
Opaque envelope components	U-value [W/m²K]	Solar absorptance [-]
Exterior walls	0.711	0.6
Adjacent walls	2.088	0.6
Exterior roof	0.225	0.6
Ceiling/interior floors	0.353	0.6
Ground floor	0.517	0.6
Glazed envelope components	Ug [W/m²K]	g-value [-]
Exterior window	1.24	0.755
Exterior skylight	1.24	0.584

The building model consists of three buildings as shown in Figure 193. Blocks BT 4-5 ans BT 1-3,9 are the oldest part and are also bridged by an above-ground tunnel used as shopping area. Block BT 7 is newest area of the mall.

Figure 193. Building blocks

	Common areas (CMA)		**Shops (SHP)**		**Midsize stores (MDS)**		**Food store (FDS)**		**Restaurant (RST)**	
	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule
People density [pers/m²]	0.14	08:00 – 20:00	0.14	08:00 – 20:00	0.14	08:00 – 20:00	0.14	08:00 – 20:00	0.14	08:00 – 20:00
Lighting density [W/m²]	35[8] 22[9]	09:00 – 20:00	358 259	09:00 – 20:00	358 259	09:00 – 20:00	279	09:00 – 20:00	288 259	09:00 – 20:00
Electric equipment [W/m²]	10	00:00 – 24:00	10	00:00 – 24:00	10	00:00 – 24:00	10	00:00 – 24:00	10	00:00 – 24:00
Heating setpoint temperature [°C]	18	09:00 – 20:00	18	09:00 – 20:00	18	09:00 – 20:00	18	09:00 – 20:00	18	09:00 – 20:00
Heating setback temperature [°C]	13.5	20:00 – 08:00	13.5	20:00 – 08:00	13.5	20:00 – 08:00	13.5	20:00 – 08:00	13.5	20:00 – 08:00
Cooling setpoint temperature [°C]	25	09:00 – 20:00	25	09:00 – 20:00	25	09:00 – 20:00	25	09:00 – 20:00	25	09:00 – 20:00
Cooling setback temperature [°C]	-	-		-		-		-		-
Ventilation rates [m³/hpx]	37.8	09:00 – 19:00	37.8	09:00 – 19:00	37.8	09:00 – 19:00	2	09:00 – 19:00	37.8	09:00 – 19:00
		19:00 – 09:00	0	19:00 – 09:00	0	19:00 – 09:00	0	19:00 – 09:00	0	19:00 – 09:00
Infiltration rates [ach]	0.5	00:00 – 24:00	0.5	00:00 – 24:00	0.5	00:00 – 24:00	0.5	00:00 – 24:00	0.5	00:00 – 24:00

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[8] This value is express in vol/h or ach

HVAC systems control and efficiency

Common areas and tenants are served by the same HVAC system .The system recovers 80% of the exhausted air and mix it with the outside fresh air. Air extractors balance the mass flow. The system is a constant air volume system and the inlet air temperature is regulated by an external sensor temperature. If the outside temperature is lower than 13°C the inlet air temperature is that one resulting from the mixture between the temperatures of the recirculated air, assumed to be 80% of the total air flow and the outside temperature. When the outside temperature is indeed greater than 13°C, the supplied air temperature is equal to the outside one. Heat recovery is taken into account by setting 60% and 40% efficiency of the heat exchanger, depending on the different blocks. This control has been set for all the days in which the shopping centre is opened.

There is a CO2 based ventilation that regulates the airflows based on the occupancy of the shopping mall. Being the whole system a constant air volume one, the airflows can just varies from the minimum to the maximum values. Since there were no information about the real airflows provided, for the modelization we follow the prescription of the European standard EN 15251, referring to a Cat II retail building (EN ISO 15251, 2008).

The mall is connected to the local district heating system which provides thermal energy for heating the whole mall. A typical dry cooler provides cooling to the newest part BT7. In BT1-3/9 and BT4-5 cooling is generated by a standard chiller coupled with an open cooling tower.

The real power plants provided by the energy manager are collected in Table 38.

Table 38. Heating and cooling system capacities

	BT 1-3/4-5/9	BT 7
Heating system capacity (kW)	8718	3500
Cooling system capacity (kW)	8694	4180

In order to estimate the electricity consumption of the HVAC system, the efficiencies in Table 39 are considered.

Table 39. HVAC efficiencies considered

	Ventilation specific power	EER	Heat Recovery	District Heating
BT 1-3-4-5-9	1.5 Wh/m³	3	60%	0.9
BT 7	0.9 Wh/m³	3.5	60%	0.9

The heating demand of the mall has been calculated by imposing a set point temperature of 18°C from 9 am to 8 pm and a setback temperature of 13.5°C during night. The cooling demand has been calculated by imposing a set point temperature of 25°C from 9 am to 8 pm. The cooling system is turned off during the night. No additional air humidification is considered during the winter time.

The heating and cooling system are shut off on Sunday and closing days.

Simulation settings

Simulations are performed with limited power and the time step is set to 15 min and a preconditioning period of a month is considered.

Two weather files are used for the analysis:

- **Typical Meteorological Year (TMY)**, which derives from Meteonorm database (Meteotest, 2015) and is representative of the standard weather conditions.

- **Actual Metereological Year (AMY)**, which derives from Weather Analytics database (Meteotest, 2015) and reports the actual weather conditions over 2013.

Actual building energy consumption

Monthly electricity profiles

The model is calibrated on the basis of monthly electricity and district heating consumption of common areas and private area in 2013, for both BT 1-3-4-5-9 and BT 7.

The model calibration has been performed using the weather file provided by Weather Analytics representing the actual meteorological year (AMY) of 2013 in Wien.

The model has been manually calibrated by considering the different age construction of the shopping mall blocks. Being added in 2010, BT7 is the newest part of the mall and so considering this aspect we decided to differentiate between lighting specific power between BT 7 zones and the rest of the mall (see input Table). For this reason, we lowered also the specific fan power for the ventilation system in BT7 zone.

According to the ASHRAE guideline 14 (ASHRAE, 2002), 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.

Since the system for heating and cooling production are different, we tried to calibrate separately the heating part and the electrical one. In our case, a CVRMSE of 4% and a NMBE of 3% is calculated on monthly basis considering only the electrical consumption that includes cooling, electrical and ventilation consumption for the whole shopping centre. Therefore, the model can be considered as calibrated.

Figure 194 and Figure 195 show the comparison between the simulated and real consumption in 2013 respectively for electricity and heating consumption.

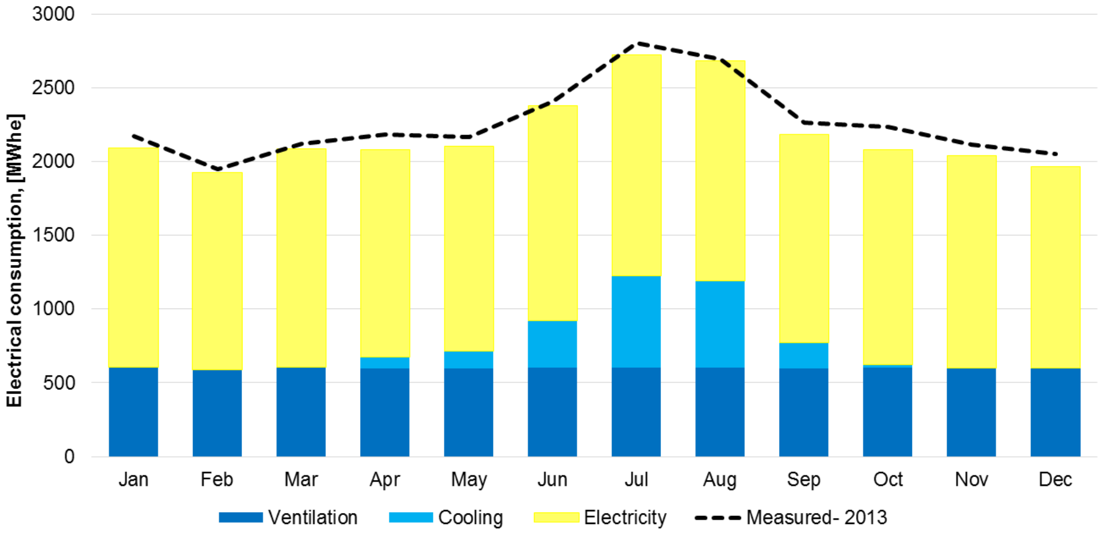


Figure 194. Monthly profile of electricity consumption from simulation results compared to the data measured in 2013 for the entire mall.

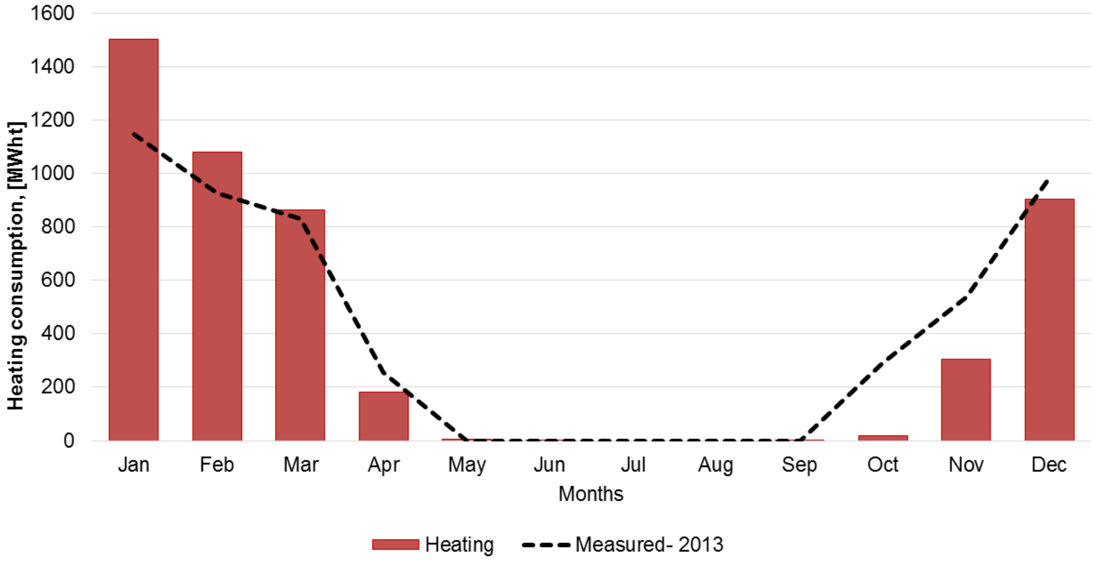


Figure 195. Monthly profile of heating consumption from simulation results compared to the data measured in 2013 for the entire mall.

According to the monitored data, the total electricity consumption for all the zones (BT 7 and BT 1-3-4-5-9) in 2013 amounts at 27153 MWh_{el} while the heating consumption is 4970 MWh_{th}. The calibrated model predicts a total electricity consumption of 26336 MWh_{el} and a heating consumption is 4863 MWh_{th}. Considering a conditioned area of 92621 m^2 the simulated electrical consuption is 284 kWh/m^2-y while the heating simulated consumption is 53 kWh/m^2-y.

Electricity consumption

The graph in Figure 196 represents the electricity consumption divided by zone function. The shop zones (SHP) have the highest electricity consumption due to the high lighting power density.

According to our model predictions, the most affecting electrical energy use are due to lighting (39% of the total electricity consumption) and ventilation (27%) followed other electric equipment (16%), by and refrigeration (11%) and finally by cooling (9%). Heating consumption since it is served by distric heating cannot be compared with the electrical consumption.

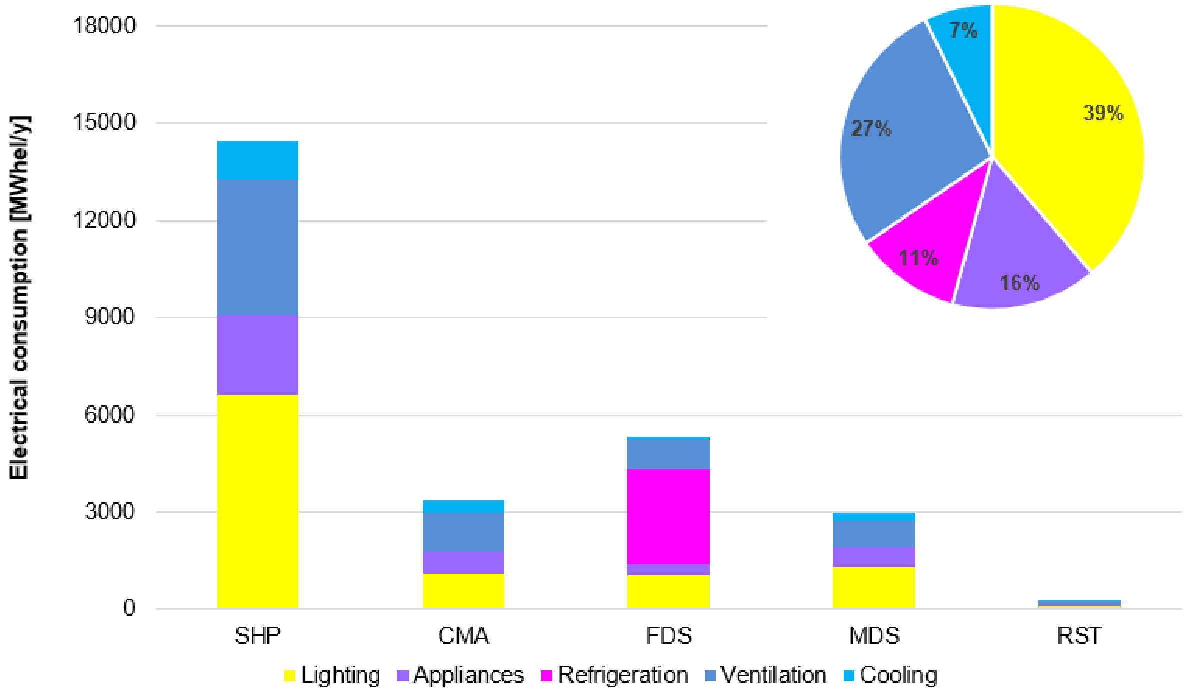


Figure 196. Electricity consumption for each group of zones: Common Areas (CMA), Shops (SHP), Midsize store (MDS), Food store (FDS), Restaurant (RST)

Total electricity consumption amounts at 26392 MWh/y which corresponds to 285 kWh/m²-y considering the conditioned area of 92621 m².These data refer to a model based on climatic condition of a typical meteorological year (TMY).

Solution sets description

The solution set here described is balanced on the specific needs of the DonauZentrum reference building and the climate conditions of Wien. Therefore, its replication in other climates or other buildings need to be further investigated.

Considering the fact that lighting is responsible for most of the electricity consumption of the mall (39%), we first decide to reduce lighting power density (**solution 1**). Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need by 80%, but increasing the heating demand that nevertheless will not affect in a deep way the primary energy consumption since the shopping mall is served by district heating.

Appliances electrical consumption account for the 16% of the total electrical consumption. Based on this data we propose **Solution 2** that account for appliances improvements such as escalators, lift, vending machine, security light, etc. in both common and private areas of the shopping mall. This solution will change as the previous one the energy balance of the building, resulting in a decreased demand for cooling since the internal gains are considerable reduced.

A further reduction of the cooling demand and consequently of its electrical consumption is the one proposed with **solution 3.** It consists in modulating the cooling set-point in the common areas according to the outdoor temperature. This will help to adapt the indoor temperature to the one outside preventing thermal shock for costumers and creating more comfortable conditions that can potential extend the permanence period of the costumers. A double beneficial effect can be considered with the solution since this will impact on both energy saving and selling. Indeed the more the time that costumers spend inside the shopping mall, the higher is the purchasing probability.

Solution 4 deals with the integration of a natural ventilation strategies in common areas in order to further reduce both cooling demand and the mechanical ventilation consumption. Existing openings, designed for smoked ventilation can indeed help vent out stale air in the hot days. Thanks to the use of natural ventilation, customers are expected to adapt easier to more relaxed comfort ranges. Therefore, temperature setpoints in the common areas can be higher according to what predict with **solution 3.**

The connection of opening control to the iBEMS and the integration of inverters automated by the iBEMS would allow to switch off the mechanical ventilation and cooling in the common areas when natural ventilation is activated and to introduce a more sophisticated control strategy.

Finally, the installation of PV plant (approximately 300 kWp) on the roof (**solution 5**) will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions.

Table 40 we give a resume of the solution considered for this reference building and in the following pages there is a detailed description of them.

Table 40. Summary of solutions

Solutions		Description
1	**Efficient Lighting system and controls**	LED installation and new control strategy
2	**Efficient Appliances**	Improvements in their efficiency in order to reduce electrical consumption
3	**Cooling set-point control**	Control of the cooling set based on outdoor conditions
4	**Natural ventilation**	Exploitation of openable windows to reduce ventilation and cooling consumption
5	**PV Plant**	Installation of PV plant on the roof to increase the self-consumption and self-production
6	**Revolving doors**	Replacement of existing entrance door with revolving doors

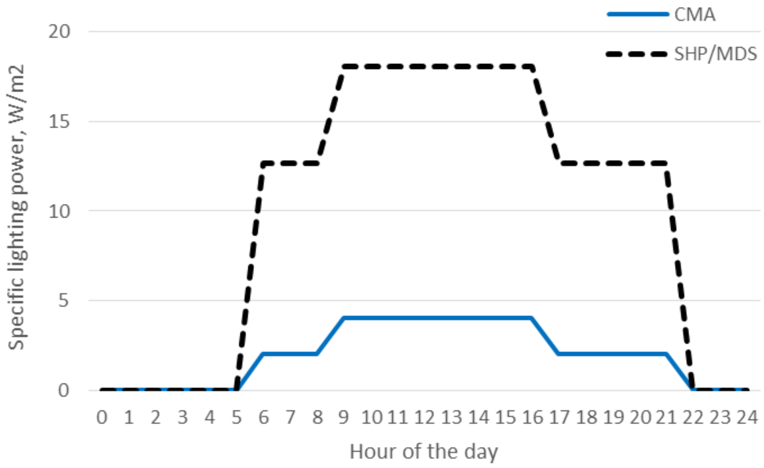
Solution 1: Efficient lighting system and controls

Objective

To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off

Description

Lighting power density is reduced down to 4.5 W/m² in the common areas and galleries and to 18.1 W/m² in the vending area (shops, midsize stores, food store) because of the installation of LED lamps.
Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.
Zonal lighting concept reduces ambient lighting, accentuates zones with higher intensity and maintains the perceived brightness impression.
The advanced controls is applied in common area and in the shopping area. For the food store and restaurant areas we decreased the value of specific lighting power by around 50% taking constant the operation time during the day.



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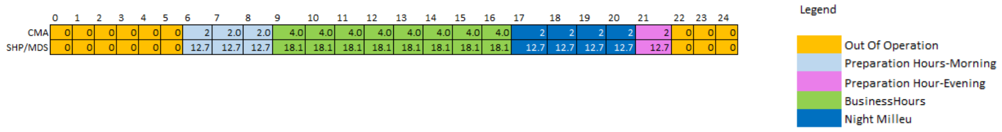


	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
CMA	0	0	0	0	0	0	2	2.0	2.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2	2	2	2	2	0	0	0
SHP/MDS	0	0	0	0	0	0	12.7	12.7	12.7	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	12.7	12.7	12.7	12.7	12.7	0	0	0

Legend

🟧	Out Of Operation
🟦	Preparation Hours-Morning
🟪	Preparation Hour-Evening
🟩	BusinessHours
🟦	Night Milleu

Area of application

Common areas, shops, midsize stores, food store and restaurant zones

Expected energy savings

45% reduction of electricity consumption due to lighting
80% cooling need reduction

Expected impact on comfort

Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall.

Interaction with other solutions

By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have an impact on building energy consumption.

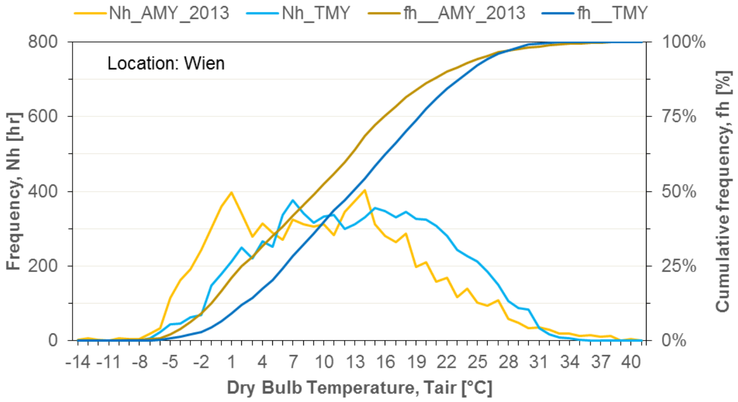
Expected investment costs

We assumed an investment cost of 10W/m²

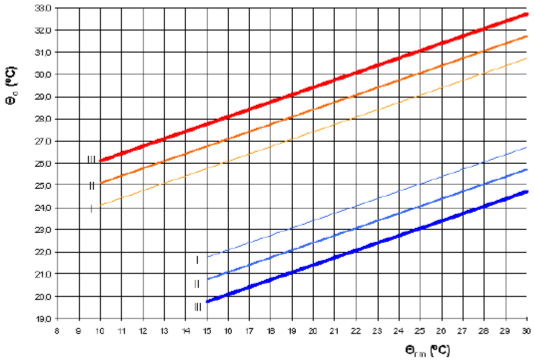
Solution 2:	**Appliance energy consumption improvements**
Objective	To reduce energy consumption for appliances by improving their efficiency
Description	Appliances is shopping centres consist of: • Distribution transformers • IT equipment (non-data center) • Water Treatment/Distribution • PCs (Laptops, Desktops, Monitors) • Cash Machines • Kitchen equipment (restaurant) • Video display/Boards • Security systems • Vending machine • Escalators • Elevators • Security lighting The appliances can be replaced in maintenance cycles with high efficiency products.
Area of application	Common Area, Shops, Medium Store department, Restaurants
Expected energy savings	46% in appliance consumption reduction; cooling consumption is reduced by 18%. Considering the whole electricity consumption a reduction by 10%.
Expected impact on comfort	The reduction of the internal gain will impact also on temperature inside the building both in winter and summer.
Interaction with other solutions	By reducing internal gain, building thermal behaviour changes reducing its cooling need. Passive solutions can now have an impact on building energy consumption.
Expected investment costs	We assumed an investment cost of 5 W/m^2 applied for 84489 m^2

Solution 3: Cooling set point control

Objective	To reduce energy consumption for cooling by using a different set point
Description	Shops conditioning is individually managed meaning that there is not a common way in ensuring comfort inside the shops. The declared cooling set-point is 25°C but lower temperature can be also registered without taking into consideration the outdoor condition. The main object of this solution is to modulate the cooling setpoint according to the outside temperature in order to prevent big temperature difference between inside and outside that can lead to thermal discomfort to costumers in both summer and mid-season. We studied the control, based on the comfort limit of the adaptive comfort theory in shops areas.



Considering the cold climate of Wien where for almost the 80% of the year outside temperature is below 25 °C (right figure), the cooling setpoint can be modulated in relation to the outdoor temperature, allowing on one side cooling demand reduction and on the other side creating a more comfortable indoor environment that interacts with the outdoor.



Cooling control strategy is based on Adaptive comfort approach (ASHRAE-55, 2013) where the limit temperatures for comfort in both summer and winter are defined according to the outdoor mean running temperature. The outdoor mean running temperature is an average of the temperature in the previous seven days. According to Category II of the adaptive thermal comfort, the cooling set-point change according to equation (1) (ASHRAE-55, 2013).

$$\vartheta_{imax} = 0.33 * \vartheta_{rm} + 18.8 + 3 \qquad (1)$$

Area of application	Shops, Medium Store department, Restaurant
Expected energy savings	90 % of cooling demand reduction
Expected impact on comfort	A better control of indoor temperature during summer and mid-season preventing thermal shock because of high temperature difference between indoor and outdoor.
Interaction with other solutions	A lower lighting power density helps in reducing cooling demand because the level of the internal gains to be offset is lowered. This is the reason why this solution comes after the reduction of the internal gains as we have seen in the previous solutions

Expected investment costs	In complex building such as shopping mall a building managements system is usually already adopted and external weather station is often used to control some parameters of the HVAC system. If this is not the case the investment costs related to this solution will be just a weather station (around 2000 €). The solution is based on the development of more precise controls.

Solution 4: Natural ventilation exploitation

Objective	To reduce energy consumption for ventilation and cooling need by exploiting existing automated openings to enhance stack natural ventilation in common areas
Description	Shopping centres are already equipped with a certain number of openable windows that are used to prevent smoke ventilation. In the Donauzentrum shopping mall, some of the skylight windows are used for natural ventilation purpose but without a specific strategy, just manually operated and the operation is based just on the energy manager judgment. Our aim is to define a ventilation control strategy in order to automatically operate and control the windows trying to optimize the used of the openable windows already present in the shopping mall. According to what proposed in solution 3, we apply also in the common area a cooling setpoint based on the adaptive comfort model.   
Area of application	Common areas
Expected energy savings	73% Cooling need reduction in common areas 30% Mechanical ventilation electricity consumption reduction in common areas
Expected impact on comfort	The use of ventilative cooling could have a great impact in indoor temperature especially during mid-season and summer. The reduced use of air conditioning in common area will have a positive impact on costumers thermal sensation, reducing the shock temperature between inside and outside usually perceived in shopping centre, but also between shops and common area being conditioned all in the same way
Interaction with other solutions	The efficacy of ventilative cooling strategies strictly depend on the level of internal gains, especially lighting power level. Before applying ventilative cooling strategies the lighting level should be lowered to its minimum (solution 1) in order to not overestimate the opening areas needed to maintain certain condition inside the common areas
Expected investment costs	They depend on the existing window controller and BMS system. We assumed a cost of about 300 €/window. Considering approximately 156 module to be controlled (considering both windows, skylights and entrance doors) we expect an investment of about 46800 €. The need also to consider the installation of at least one sensor of indoor temperature and operative temperature within all common areas included in the ventilation strategy. We account for 150€/sensor including installation costs. The total investment for this solutions should be around 53790 € for construction, installation and engineering.

Solution 5: Photovoltaic plant	
Objective	Installation of PV plant (139 kWp) on the roof to increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO_2 emissions.
Description	The PV plant can improve the “green-energy” produced on-site and decrease the energy imported from the grid. If well dimensioned, the percentage of self-coverage can be up to 80% based on the annual energy consumption. 
Area of application	The red areas in the figure above are the one identified as suitable for the PV installation. In total it is about 1838 m^2.
Expected energy savings	With this solution part of the electricity consumption can be covered combined with a self-electricity production with enclosed CO_2 emissions reduction.
Expected impact on comfort	No impact on thermal comfort since it will be potentially installed on the roof of the shopping mall.
Interaction with other solutions	The PV plant has been dimensioned to potentially cover the electricity consumption for lighting and appliances on the common areas and the lighting consumption of all the restaurant areas.
Expected investment costs	We estimate a total cost of 1600 €/kWp. Considering 139 kWp installed, the total investment cost is around 222’788 €.

Solution 6: Revolving doors	
Objective	Installation of revolving doors to reduce the infiltration losses
Description	The reduction of the infiltration losses can be operated by using revolving doors which contribute to keep an energy efficient building by regulation its temperature and air pressure. Thanks to the design of revolving doors, much less air rushes out when people exit and enter through them.
	
Area of application	Common Area entrance
Expected energy savings	30% of heating demand reduction 25% of infiltration losses reduction
Expected impact on comfort	The impact on thermal comfort is expected especially in the zone adjacent to entrance where the possibilities of cold draughts, especially during winter season are consistently limited.
Interaction with other solutions	The reduction of the infiltration losses by using revolving doors will affect natural ventilation solution since the entrance doors where used as part of the ventilation strategy. In this case new dedicated openings should be designed.
Expected investment costs	Five revolving doors with an approximate cost of 400’000 €/each. The costs depends also on the design of the revolving doors.

Results

In this section we are going to present the results of the solutions proposed that comes out from simulations.

Energy and operative costs savings

The graph in Figure 197 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described before, up to solution 3.

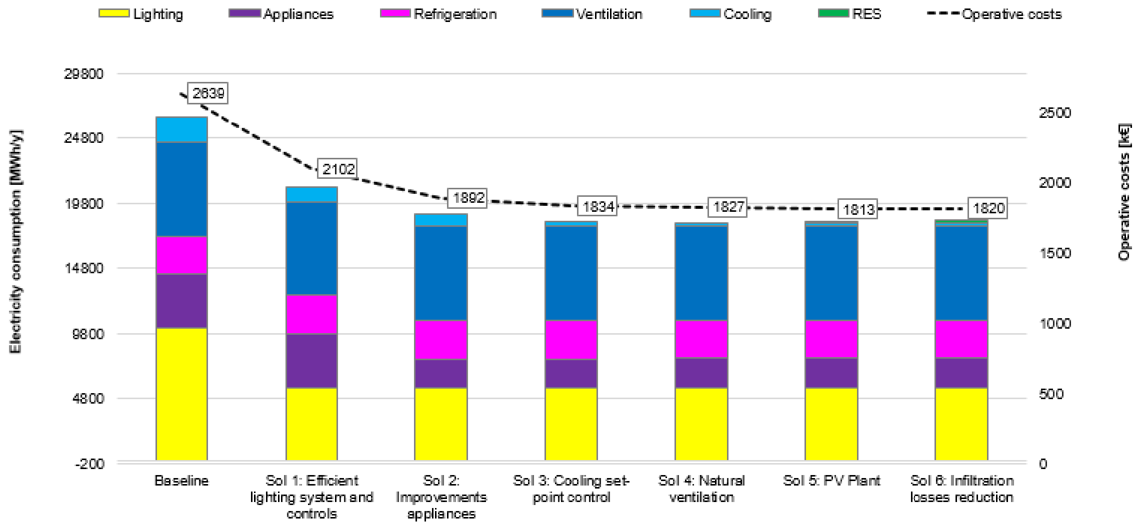


Figure 197. Yearly electricity consumption and operative costs.

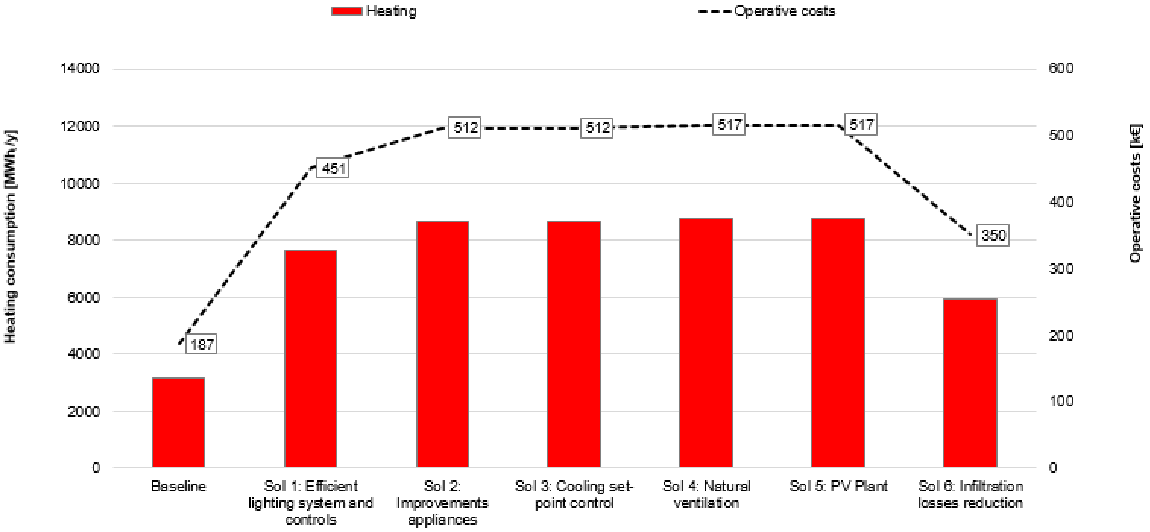


Figure 198 Yearly heating consumption and operative costs

Figure 198 shows the yearly heating consumption and its operative costs while in Figure 199 we are able to aggregate all the consumption in term of primary energy .The whole operative cost and primary energy savings that can be reached are also showed.

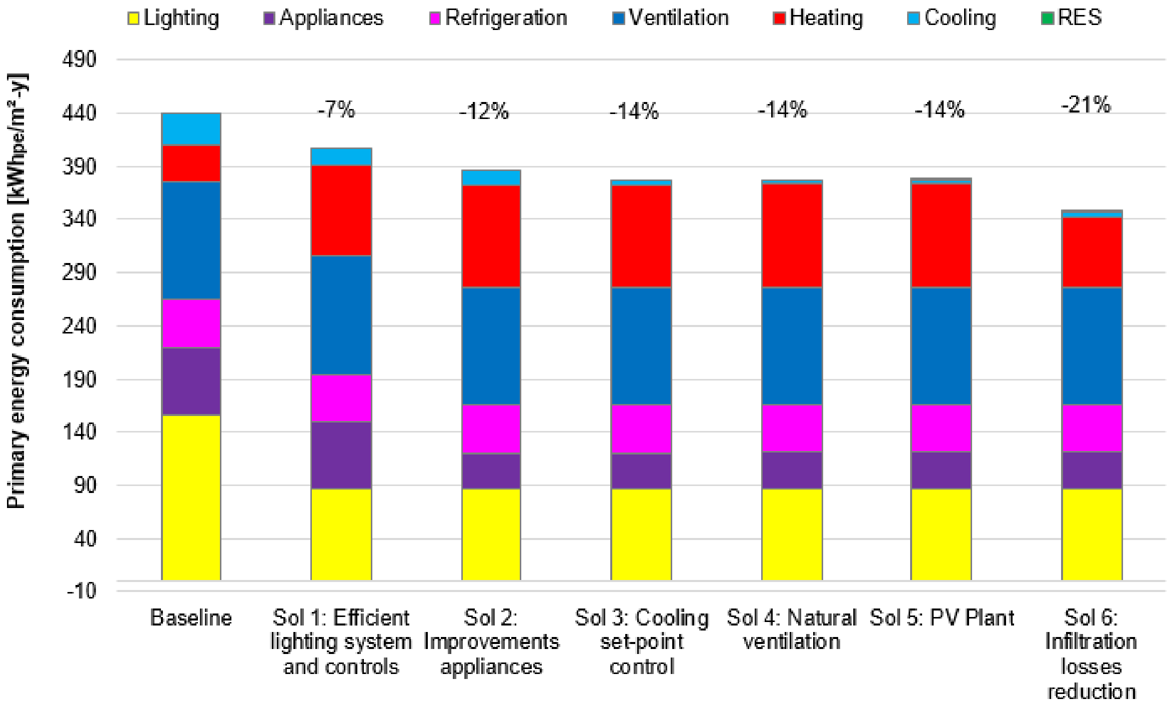


Figure 199. Primary energy consumption and related energy savings

Economic analysis

The economic analysis is based on the assumption collected in Table 41 and Table 42.

Table 41. Assumptions on cost of investment of the solution sets

Equipment	Cost
Efficient and dimmerizable lamps	926’210 €
Appliances improvements	422’445 €
Weather station	2’000 €
Windows automation and controls	48’900.00 €
PV plant	222’400 €
Revolving doors	2’000’000 €
Installation cost (in average 20% of equipment cost)	1’337’164 €
Engineering and permitting (8% of the equipment cost)	139’956 €
Total	5’099’074 €
Tax (20%)	1’019’815 €
Total cost of investment (incl. tax)	6’118’889 €

Table 42. Economic analysis assumptions

Assumptions	Value
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	0 - 8%

Energy costs	
Cost of electricity	0.10 €/kWh
Cost of district heating[10]	0.059 €/kWh
Electricity buy price annual variation	1.0%/year
Electricity sell price annual variation	1.0%/year
Installation ageing	0.5%/year
Operation costs	
Insurance	0.5%
Taxes	0%
Maintenance	3%
Miscelaneous supplies	0.2%
Contingency	10% from previous concepts
Annual variation	0.5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**. The results of the cash inflows and outflows is shown over the 25 years period studied.

Table 43 Economic analysis on stacked measure

Solution		Investment individual solution [€]	Total investment [€]	Operation cost savings [€/year]	Energy savings [MWh/year]	Energy savings [%]	ROI [%]	Pay Back Time [years]	Net Present Value [€]	Discounted Pay Back Time [years]	Discounted Net Present Value [€]
1	Efficient lighting system and control	926’210€	1’500’460 €	272’759 €	5374	20	18.9	5.4	4,594,466 €	7.28	1,242,678 €
+ 2	Efficient Appliances	422’445€	2’184’821 €	422’087 €	7471	28	21.7	4.7	7,463,745 €	6.10	2,187,242 €
+ 3	Cooling set-point control	2’000 €	2’187’461 €	479’936 €	8050	30	25.4	4.1	9,009,857 €	5.05	2,833,943 €

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[10] Source: Gegenüberstellung der Endenergie des Stroms für das Chemiehochhaus Bestand und das Plus-Energie-Gebäude in kWh/a (Daten 2008, 2009: TU Wien Gebäude und Technik)

+ 4	Natural ventilation	48’900 €	2’252’009 €	482’627 €	8124	31	25.5	4.1	9,018,072 €	5.05	2,837,370 €
+ 5	PV plant	222’788 €	2’518’889 €	496’627 €	8264	31	25.7	4.0	9,102,619 €	5.0	2,872,731 €
+ 6	Revolving doors	2,000,000 €	6,118,889.1 €	655’827 €	8194	31	32.7	3.2	11,972,881 €	3.8	4,074,609 €

The results of the cash inflows and outflows for the whole solution set are shown over the 25 years period studied are shown in the graphs in Figure 200 and Figure 201.

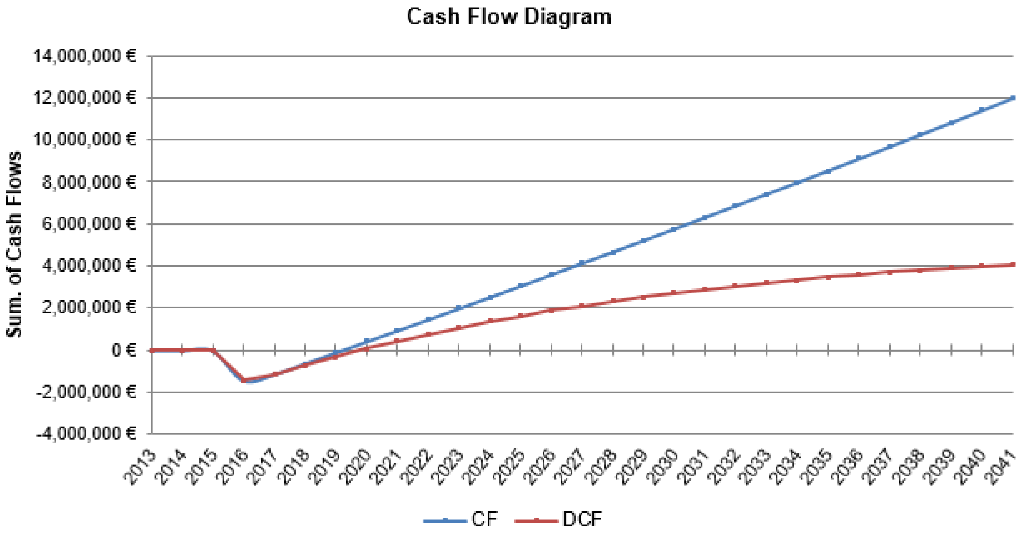


Figure 200 Cash flow diagram for the solution-set when discount factor is equal to 8%

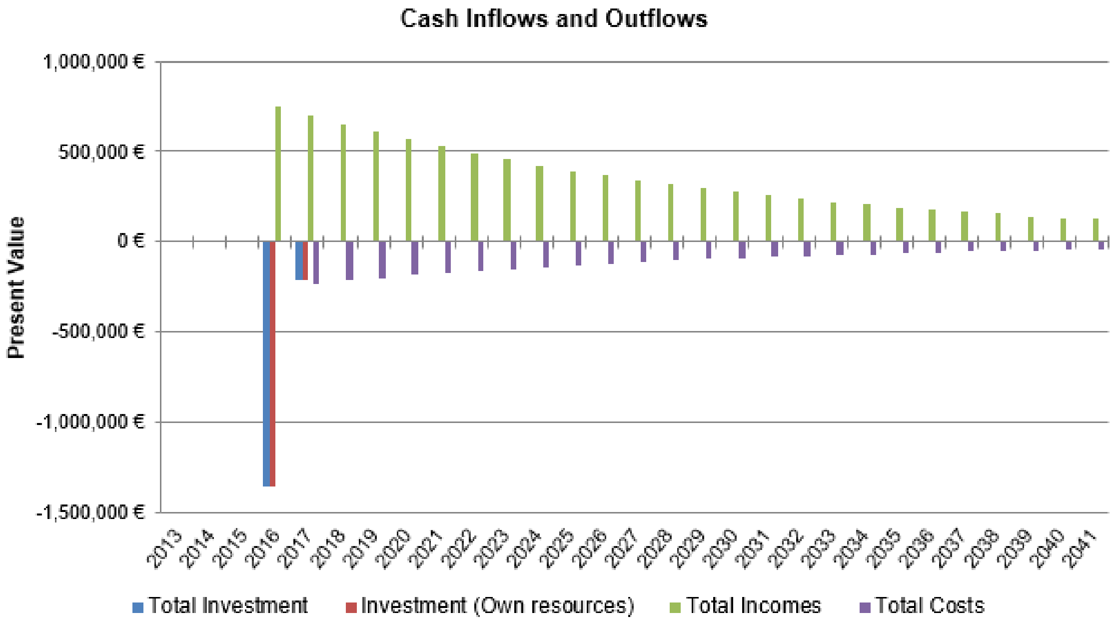


Figure 201 Cash Inflow and Outflow for the solution-set when discount factor is equal to 8%

Conclusions

The document presents the proposed solution set for the Donauzentrum reference building, located in Wien.
The solution-set proposed includes:

- Solution 1: Efficient lighting system and controls
- Solution 2: Appliance energy consumption improvements
- Solution 3: Cooling set point control
- Solution 4: Natural ventilation exploitation in common areas
- Solution 5: Photovoltaic plant
- Solution 6: revolving doors

The Integrated Modelling Environment developed within CommONEnergy project allowed us to take into account the interaction between solutions and to assess the overall energy savings of the solution set packages and of each solution stacked on the previous applied ones.
The solution set package proposed can lead to a reduction of **21%** of primary energy consumption.
Considering the expected investment cost related to each solution, a total investment cost of around **6’118’889 €** is estimated (incl. tax).
With an average cost of electricity of **0.10 €/kWh** and **0.059 €/kWh** for the district heating, the energy saving due to energy conservation and efficiency measures are foreseen to be around **655,827 €** in the first year of operation after retrofit.
The estimated Pay Back Time for this solution-set is expected to be between **3.2 and 3.8 year** with a discount factor range of 0-8%.
A summary of the solution-sets studied and the economic assessment performed was shown in **Error! Reference source not found.**.
For the specific case of the Donauzentrum the target of 75% of primary energy reduction was very ambitious and it was well known since the beginning of the feasibility study. The management of the shopping centre is investing regularly on sustainable solutions for the shopping centre. Considering this aspect, we tailor-made the study considering both solutions with high probability of being applied such as new efficient lighting and control and the natural ventilation exploitation in common areas, and suggestion on other solution that can be beneficial in terms of operating costs and return of investment.

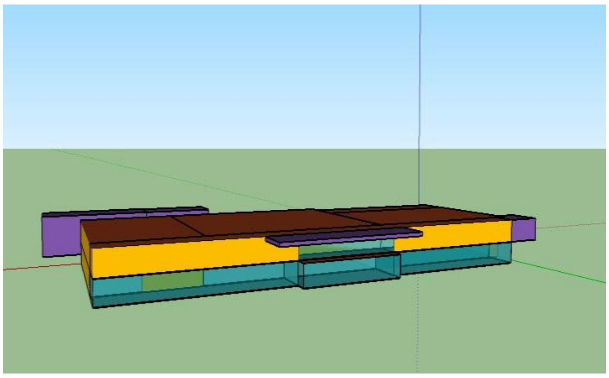
Intrinsic factors did not allow us to reach the goal in terms of primary energy reduction; nevertheless, the payback time of the solution set proposed makes the solution set a convenient action for the shopping centre management

Pamarys (Silute - Lithuania)

Building model: input data summary

General data	
Gross floor area [m²]	6,020
Number of opening hours per day [h/d]	12
Number of opening days per week [d/w]	6

Thermal zone model



Number of thermal zones	12
First floor height [m]	3
Second floor height [m]	3.1

Zone typology	Zone group area [m²]
Shops	3,806.45
Restaurant	1,000.62
Common area	1,024.4
Warehouse	741.48

Building envelope

Opaque envelope components	U-value [W/m²K]	
External wall	0.542	
Roof	0.325	
Ground floor	0.530	
Glazed envelope components	**Ug [W/m²K]**	**g-value [-]**
Exterior window	1.06	0.626

	Common areas		**Shops**		**Restaurant**		**Warehouse**	
	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule
People density [pers/m^2]	0.14	8:00 – 21:00	0.14	8:00 – 21:00	0.14	8:00 – 21:00	0	-
Lighting density [W/m^2]	23.68	8:00 – 21:00	36.17	8:00 – 21:00	28.2	8:00 – 21:00	30	8:00 – 21:00
Electric equipment [W/m^2]	0	8:00 – 21:00	5	8:00 – 21:00	5	0:00 – 24:00	5	8:00 – 21:00
Heating setpoint temperature [°C]	20	8:00 – 20:00	20	8:00 – 20:00	20	8:00 – 20:00	18	8:00 – 20:00
Cooling setpoint temperature [°C]	25	8:00 – 20:00	25	8:00 – 20:00	25	8:00 – 20:00	25	8:00 – 20:00
Ventilation rates [kg/hr·m^2]	7.35	8:00 – 21:00	7.35	8:00 – 21:00	7.35	8:00 – 21:00	2.35	8:00 – 21:00
Infiltration rates [ach]	0.55	0:00 – 24:00	0.55	0:00 – 24:00	0.55	0:00 – 24:00	0.55	0:00 – 24:00

HVAC systems control and efficiency

Energy demand for space heating and hot water is supplied by the furniture factory heating power plant which is next to the Shopping centre.
Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time.
No information about the HVAC and refrigeration plant layout of the supermarket are available.

Heating and cooling:

It has been assumed no cooling needs. Almost constant electrical profile during the whole year with a little increase in summer (could be for the ventilation) and external temperatures are below 26ºC during almost the whole year.

Ventilation:

To maintain the temperatures in summer it has been assumed free cooling from middle of May (3,150h) to middle of September (6,500h). The schedule is from 00:00 to 8:00, with 6 renovations/hour. During this period (opening time) has been also increased the ventilation values at four times.
During heating periods: Heat recovery efficiency with a performance of 72%. (Selected for the calibration).

Simulation settings

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time. The time step is set to 15 min and a preconditioning period of a month is considered.
Weather file used for the analysis refer to the **Typical Meteorological Year (TMY)**, which derives from Meteonorm database (Meteotest, 2015) and is representative of the standard weather conditions.

Actual building energy consumption

Electricity profile

Comparison between real electricity consumption in 2013 and simulation results:

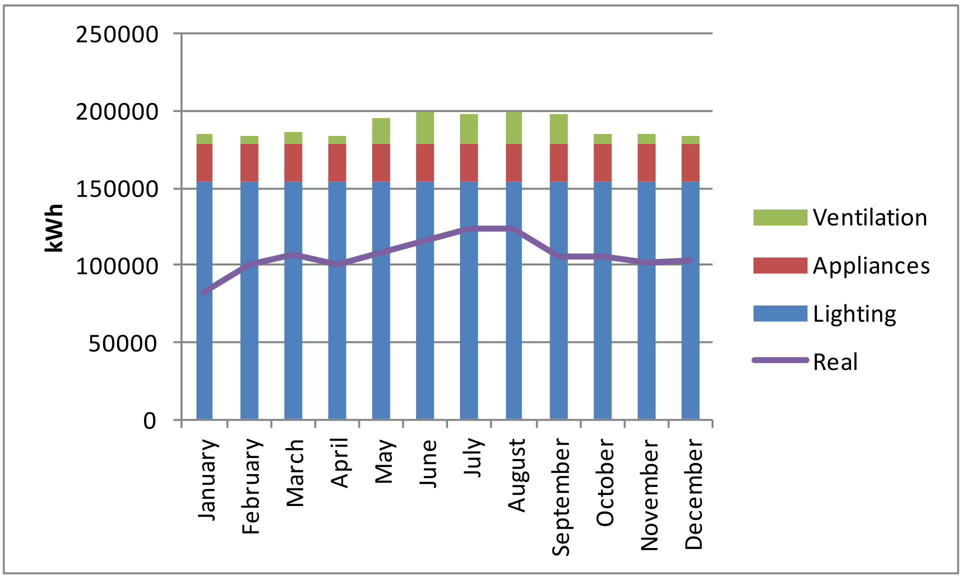


Figure 202. Real electricity consumption of the building for 2013 VS simulation results

All the electricity consumption is due to lighting, ventilation and auxiliaries, not influencing the cooling (assuming no cooling needs) and heating (district heating).

The higher electrical consumption obtained with the simulation (Figure 202) could be due to the use of very high standard values for the lighting density as basecase. In case we use lower values as basecase, the comparison between real and simulation is quite similar as can be seen in the following picture (Figure 203) and using these values (Restaurant: 10 W/m²; Shops: 15 W/m²; Common areas: 10 W/m²; Warehouse: 5 Wm²).

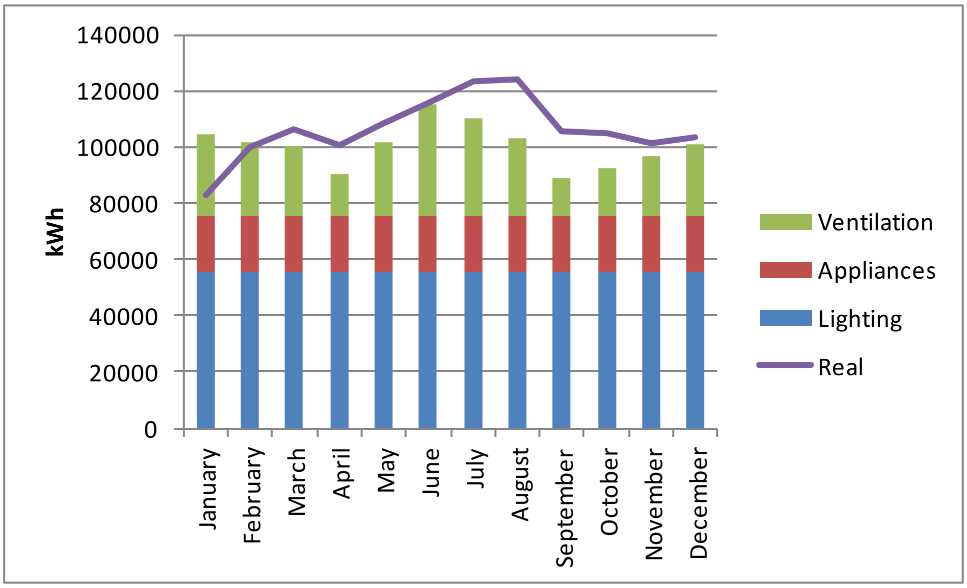


Figure 203. Real electricity consumption of the building for 2013 VS simulation results with lower lighting density

The values of the indicators after the calibration are reported in Table 8.

Table 44. Tolerances values summary.

Type of consumption	Indicator	Tolerance (%)	Target tolerance (%)
Electricity	CVRMSE	10.27	<15

	NMBE	0.05	<5

Heading profile

Figure 204 shows the comparison between the real heating consumption in 2013 and the simulation results. Values in summer months have been assumed only as part of DWH. In the rest of the months out of summer a similar value for DHW has been assumed as part of DHW.

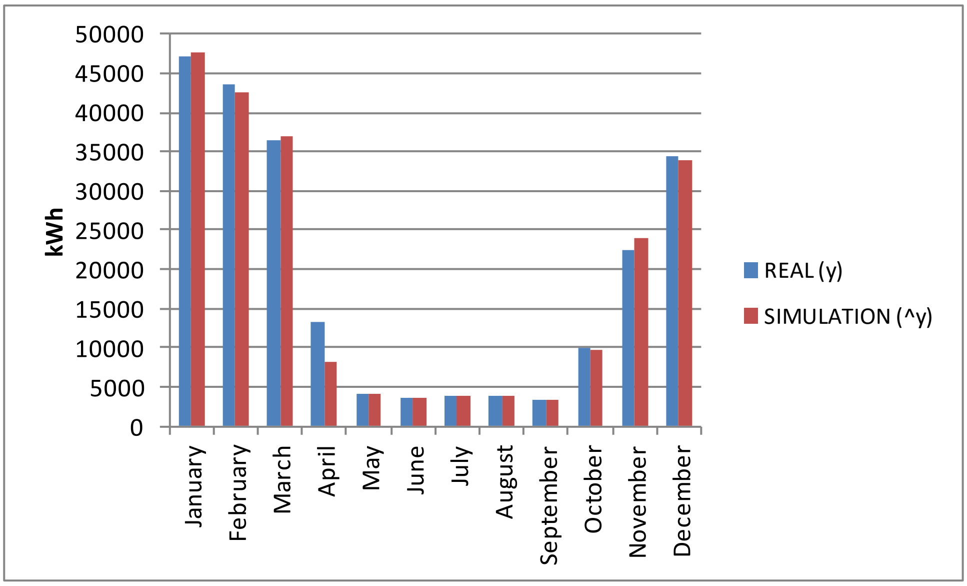


Figure 204. Comparison between real data consumption for heating in 2013 and simulation results

The values of the indicators after the calibration are reported in Table 45.

Table 45. Tolerances values summary.

Type of consumption	Indicator	Tolerance (%)	Target tolerance (%)
Heating	CVRMSE	14.46	<15
	NMBE	2.79	<5

Electricity consumption

The graph in Figure 205 represents the electricity consumption divided by zone function.

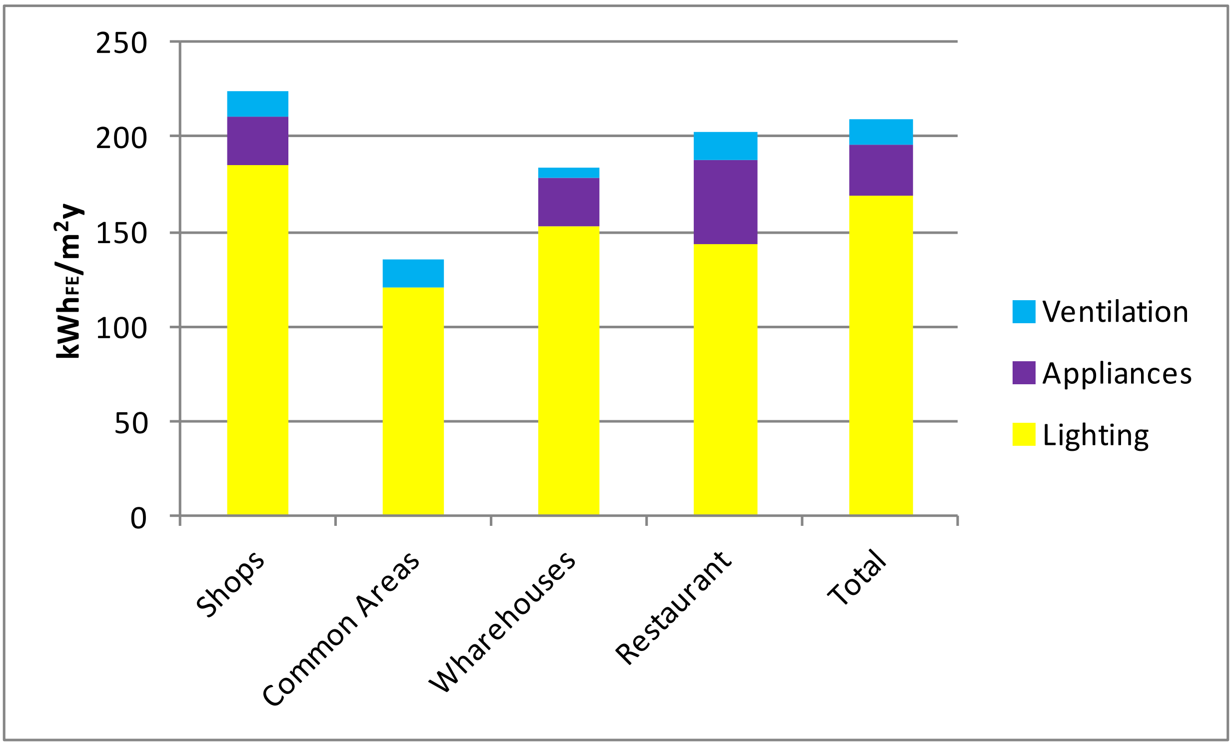


Figure 205. Electricity consumption for each group of zones: Common Areas (CMA), Shops (SHP), Warehouses (WRH), Restaurant (RST)

Solution sets description

The solution set here described is balanced on the specific needs of Pamarys reference building and the climate conditions of Silute.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decide to reduce lighting power density and to set-up a control strategy during the preparation hours, i.e. before the public opening of the building **(solution 1)**. Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need but increasing the heating demand.

The **solution 2** aims to reduce the heating demand that was increased after the reduction of lighting internal gains. This consists in improvements in the envelope, increase in the efficiency of the heat recovery and variations in the heating set points.

Finally, the installation of RES systems (PV + Wind Power) **(solution 3)** will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO_2 emissions.

Solution 1: Effective artificial lighting equipment + control strategies

Objective

To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off
With this solution is possible to reduce the electricity consumption of the building. By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have a higher impact on building energy consumption (this solution would be very interesting in combination with Solution 2).

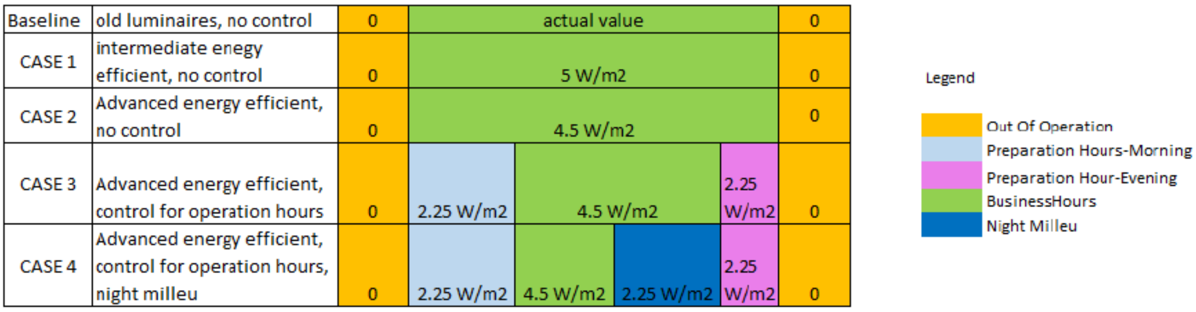
Description

Four different cases have been studied:

- Case 1: Intermediate energy efficient lighting with no control.
- Case 2: Advanced energy efficient lighting with no control.
- Case 3: Advanced energy efficient lighting with control for operation hours.
- Case 4: Advanced energy efficient lighting with control for operation hours and night milieu.

Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.

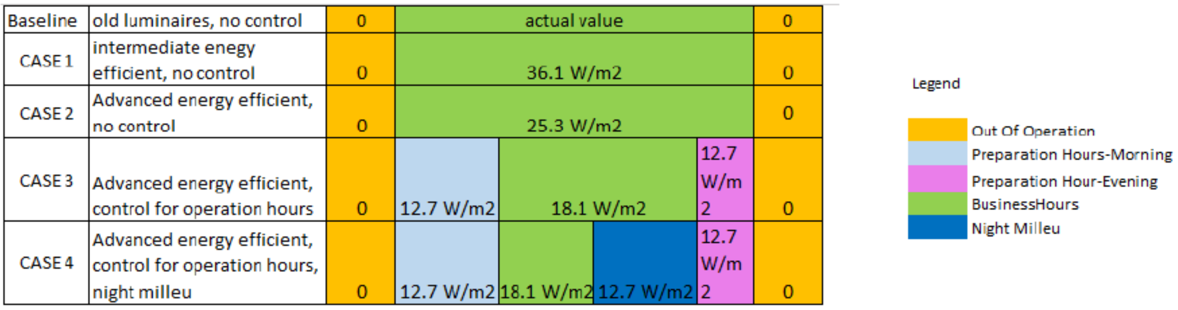
For common areas:



Baseline	old luminaires, no control	0	actual value				0
CASE 1	intermediate enegy efficient, no control	0	5 W/m2				0
CASE 2	Advanced energy efficient, no control	0	4.5 W/m2				0
CASE 3	Advanced energy efficient, control for operation hours	0	2.25 W/m2	4.5 W/m2		2.25 W/m2	0
CASE 4	Advanced energy efficient, control for operation hours, night milleu	0	2.25 W/m2	4.5 W/m2	2.25 W/m2	2.25 W/m2	0

Legend
🟨 Out Of Operation
⬜ Preparation Hours-Morning
🟪 Preparation Hour-Evening
🟩 BusinessHours
🟦 Night Milleu

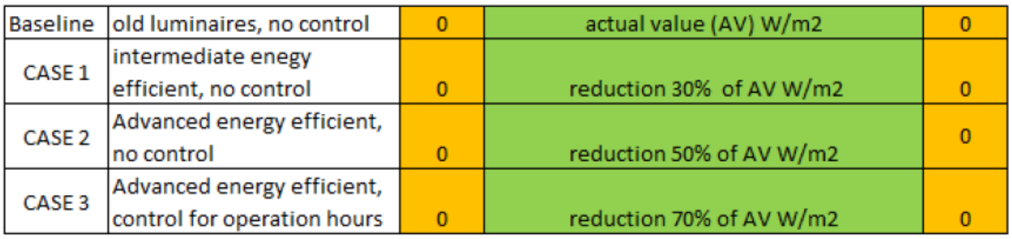
For shops:



Baseline	old luminaires, no control	0	actual value				0
CASE 1	intermediate enegy efficient, no control	0	36.1 W/m2				0
CASE 2	Advanced energy efficient, no control	0	25.3 W/m2				0
CASE 3	Advanced energy efficient, control for operation hours	0	12.7 W/m2	18.1 W/m2		12.7 W/m2	0
CASE 4	Advanced energy efficient, control for operation hours, night milleu	0	12.7 W/m2	18.1 W/m2	12.7 W/m2	12.7 W/m2	0

Legend
🟨 Out Of Operation
⬜ Preparation Hours-Morning
🟪 Preparation Hour-Evening
🟩 BusinessHours
🟦 Night Milleu

For rest of areas:



Baseline	old luminaires, no control	0	actual value (AV) W/m2	0
CASE 1	intermediate enegy efficient, no control	0	reduction 30% of AV W/m2	0
CASE 2	Advanced energy efficient, no control	0	reduction 50% of AV W/m2	0
CASE 3	Advanced energy efficient, control for operation hours	0	reduction 70% of AV W/m2	0

Area of application

Artificial lighting of the shopping mall.

Expected energy savings

Case 1: 12% reduction in lighting consumption.
Case 2: 37% reduction in lighting consumption.
Case 3: 58% reduction in lighting consumption.

Case 4: More than 60% reduction in lighting consumption.

Expected impact on comfort	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping centre.
Expected investment costs	LED lighting: 4 €/m² (min.price, standard product). LED lighting: 14 €/m² (max. price, dimable, A++ product).

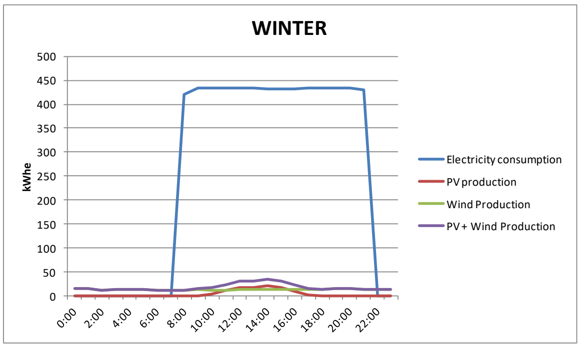
Solution 2: Energy efficiency measures
· Improvements in the envelope
· Heat recovery
· Variation of heating set point

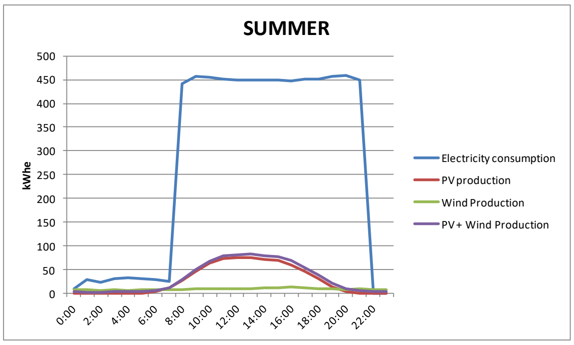
Objective	With this solution is possible to: • Reduce the heating demand of the building. •
Description	Improvements in the envelope: After a parametric analysis of the insulation: Walls (From 5 cm to 15 cm), Roof (From 10 cm to 20 cm), and Floor (From 7 cm to 20 cm). Heat recovery: Increase in 5%. Variation of heating set point: Change the heating set point from 20ºC to 19ºC.
Area of application	Improvements in the envelope: Walls, Roof, Floor. Heat recovery: HVAC system. Variation of heating set point: Control of the HVAC system.
Expected energy savings	Reduction in more than 40% of heating demand in case of application together with Solution 1.
Expected impact on comfort	Improve the comfort during the occupied hours. Softening discomfort due to overheating especially in summer and mid-season period
Expected investment costs	Improvements in the envelope: Insulation cost 100 €/m^3 Heat recovery: 6.2 €/m^{3}h Variation of heating set point: No investment cost; it is just based on changing controls.

Solution 3: RES integration (PV panels + Wind turbine)

Objective On site RES are a good solutions to produce electricity increasing the self-consumption and self-production and thus reduce the amount extracted from the grid.

Description Good weather conditions for the integration of RES, located in the outskirts of Silute without obstacles and with surface available on the roof (total roof area: 1,500 m²), The photovoltaic generation profile is suitable for the demand profile of the building because the photovoltaic generation peaks coincide with the market demand peaks. It is possible to install a PV installation on the roof covering the total roof area available (around 1,500 m²).
It is possible to install a medium-size (150 kW) wind turbine system, due to the climatologic conditions (wind speed ~ 5 – 6 m/s) and without buildings surrounding the shopping mall.





Load profiles will change due to other solutions.

Area of application Roof

Expected energy Production The yearly simulation performed give us the following energy production estimation:
Wind Power: 82,738 kWh/y
Photovoltaic: 156,393 kWh/y

Expected investment costs PV system: 1,000 €/kW
Wind turbine: 3,000 €/kW

Results

Energy and operative costs savings

The graph in Figure 2-3 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described in par. 0.

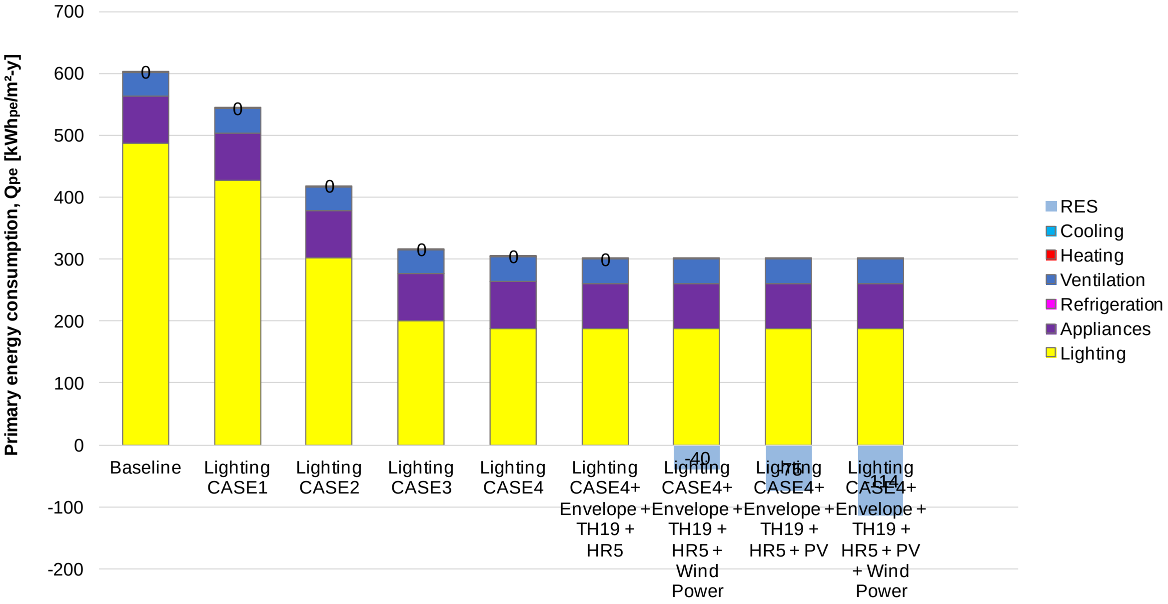


Figure 206. Yearly final energy consumption

Economic analysis

Table 46. Economic analysis assumptions

Assumptions	Value
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	5.08%
Energy costs	
Cost of electricity	0,1324 €/kWh
Cost of district heating	0.05797 €/kWh
Electricity buy price annual variation	3%/year
Electricity sell price annual variation	3%/year
Installation ageing	0.5%/year
Insurance	
Insurance	0.5% for PV 0.3% for WP
Taxes	15%
Maintenance	2.5% for PV 4% for WP

Contingency	5% from previous concepts
Annual variation	0.5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**.
The results of the cash inflows and outflows is shown over the 25 years period studied are shown in the graphs.

Solutions		Description
1a	**Lighting**	LED standard product

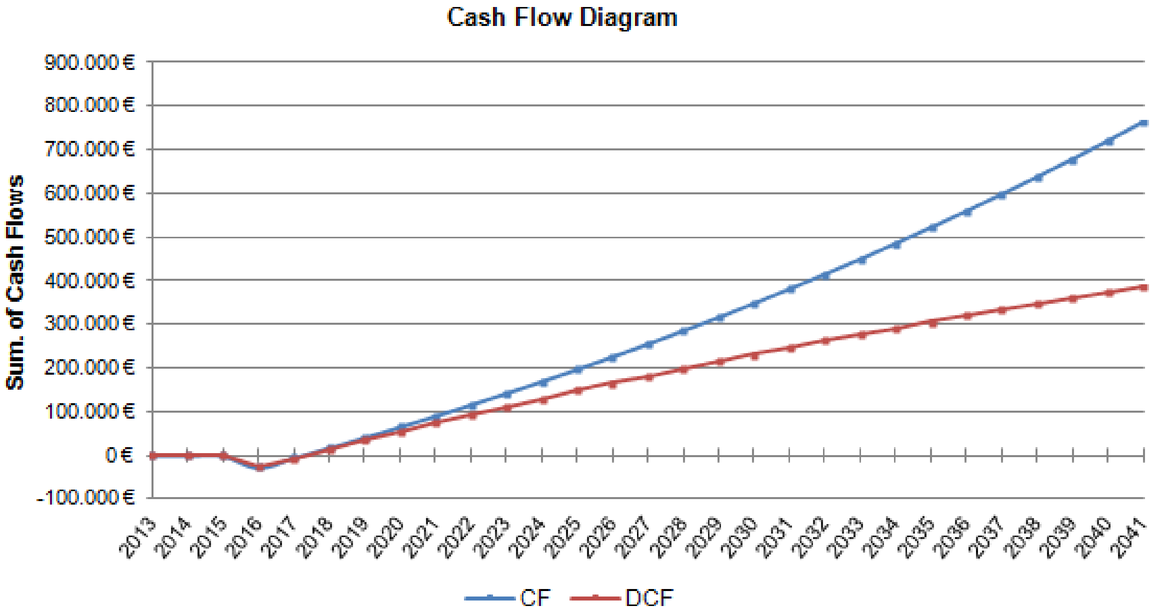


Figure 207. Cash flow diagram S1a

The installation of standard (LED) would have a ROI period of 1.3 years.

Solutions		measures
1a	**Lighting**	LED standard product
1b	**Lighting**	LED dimable, A++ product

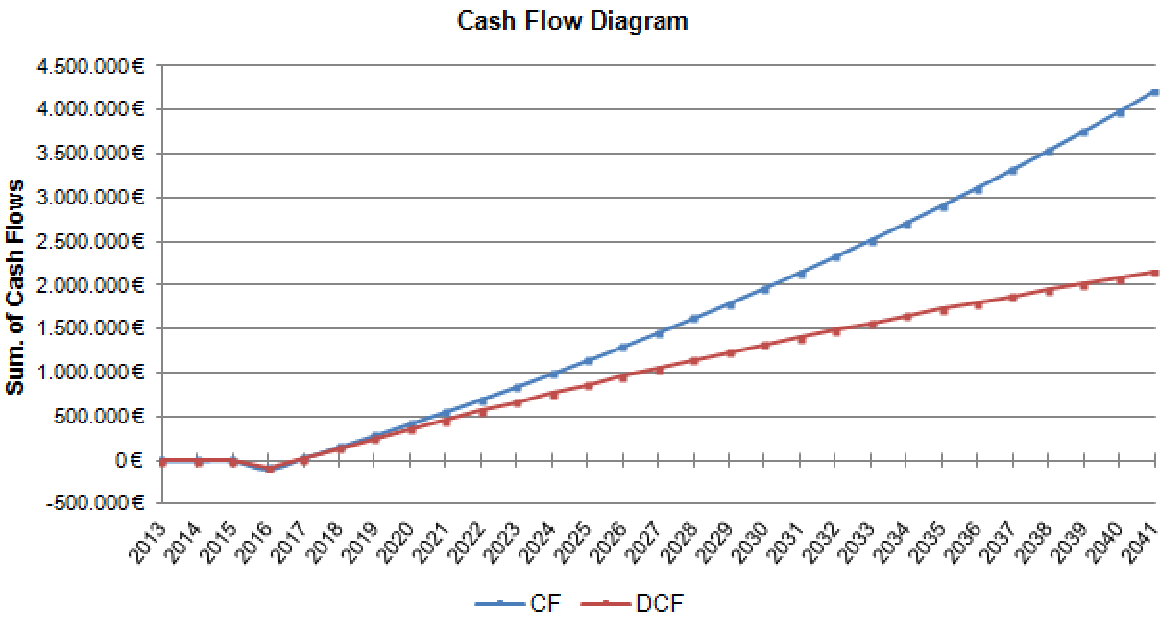


Figure 208. Cash flow diagram S1b

The installation of efficient lighting (LED) with better control strategy would have a ROI period of less than 1 year.

Solutions		Description
1a	**Lighting**	LED standard product
1b	**Lighting**	LED dimable, A++ product
2	**Energy efficiency measures**	Improvements in the envelope Heat recovery Variation of heating set point

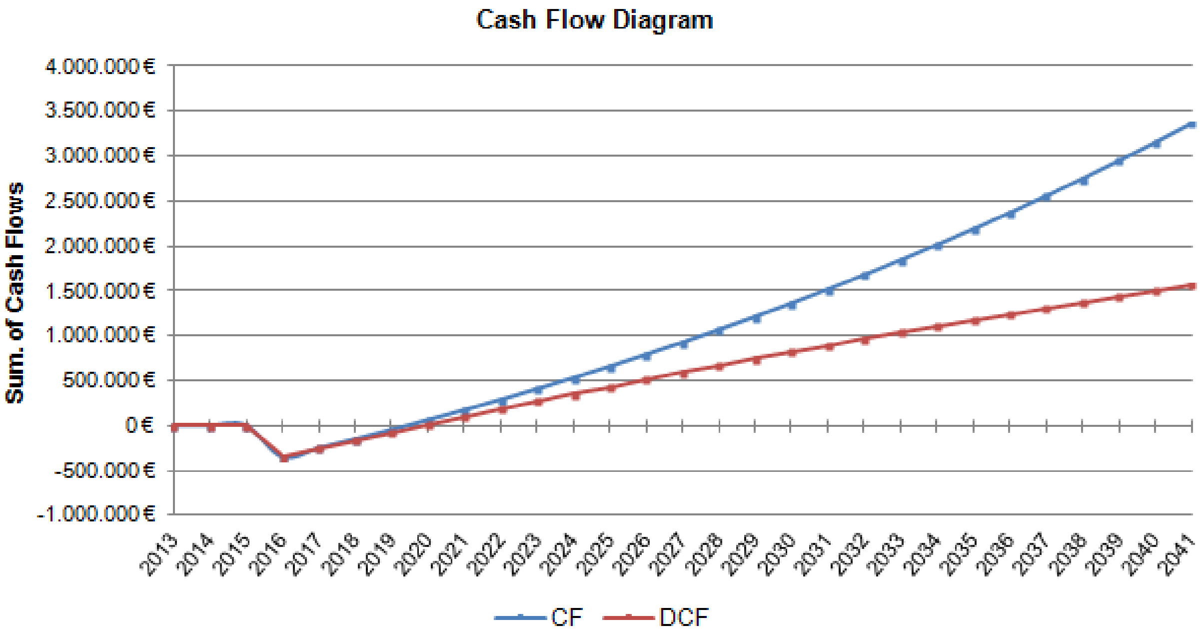


Figure 209. Cash flow diagram S1b-2

The installation of efficient lighting (LED) with better control strategy, addition of energy efficiency measures would have a ROI period of 3.89 years.

Solutions		Description
1a	**Lighting**	LED standard product
1b	**Lighting**	LED dimable, A++ product
2	**Energy efficiency measures**	· Improvements in the envelope · Heat recovery · Variation of heating set point
3a	**RES**	PV

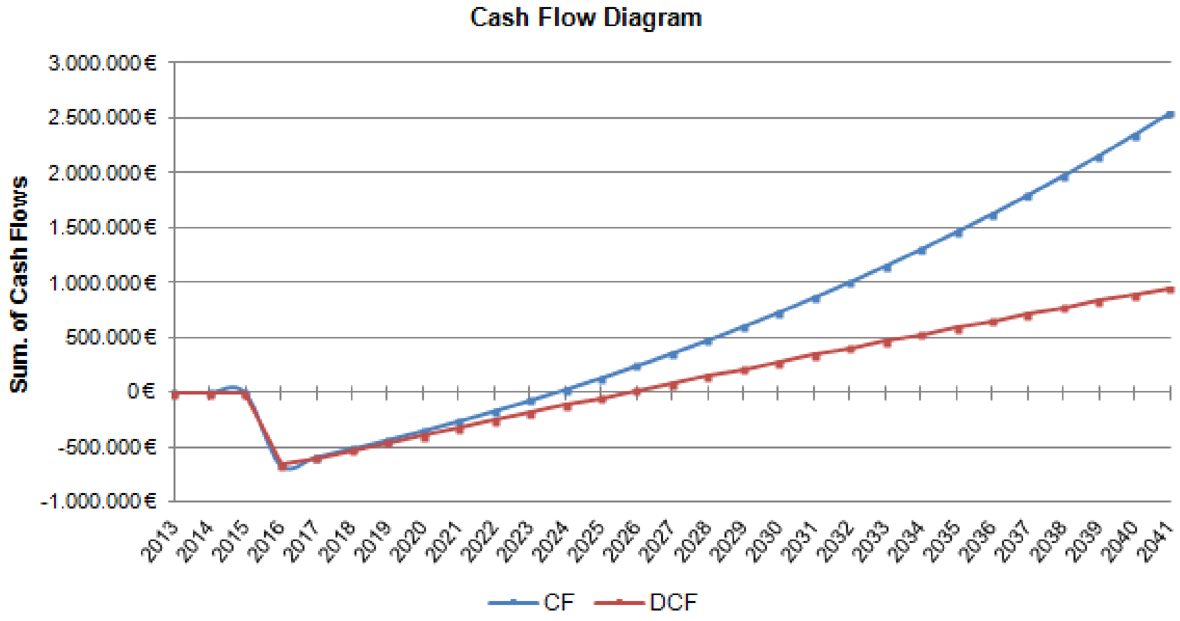


Figure 210. Cash flow diagram S1b-2-3a

The installation of efficient lighting (LED) with better control strategy, addition of energy efficiency measures and PV would have a ROI period of 6.29 years.

Solutions		Description
1a	**Lighting**	LED standard product
1b	**Lighting**	LED dimable, A++ product
2	**Energy efficiency measures**	Improvements in the envelope Heat recovery Variation of heating set point
3a	**RES**	PV
3b	**RES**	Wind Power

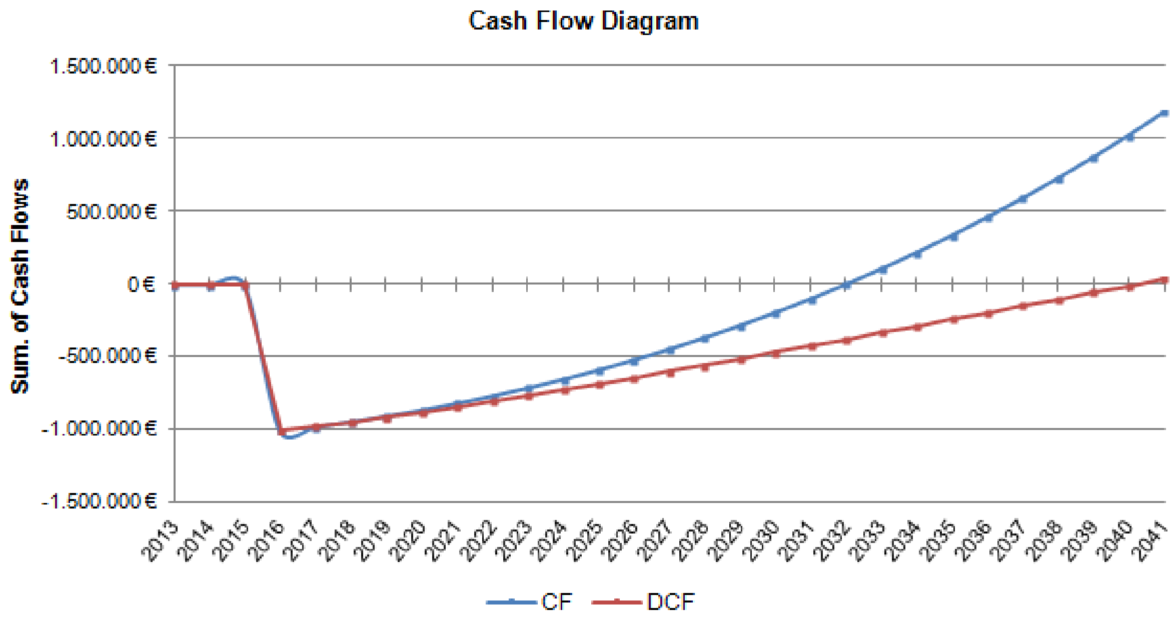


Figure 211. Cash flow diagram S1b-2-3a-3b

The installation of efficient lighting (LED) with better control strategy, addition of energy efficiency measures and PV+WP would have a ROI period of 24.19 years→ Out of scope (<7 years).

Conclusions

The energy simulation model of the Pamarys reference building has allowed us to predict energy consumption and test and quantify potential energy savings with different solutions. For the development of the energy simulation model has been used mainly real information coming from the reference building, but on the other hand, for some aspects in which the information has not been possible to be collected, has been needed to use some assumptions indicated within this document and which need to be cross checked.

After developing several simulations implementing both passive solutions (energy efficiency measures) and active solutions (artificial lighting and RES), we have obtained the conclusion that could have a great potential of improvement. With the energy efficiency measures here described, it would be possible to reduce in a high amount the heating demand of the building and thus the expenses due to the district heating. With the advanced artificial lighting systems it is possible to reduce in a high amount the electrical consumption and thus reduce the electricity bill. With the RES it is possible to cover part of the electricity demand of the building and in this way to reduce the electricity coming from the grid.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decided to reduce lighting power density **(solution 1)**. This solution with an investment of 92,000 € offered almost 49% of primary energy savings. The implementation of solution 1 would have a payback of less than 1 year.

Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need, but increasing the heating demand. Therefore, a complete retrofit with insulation layer, heat recovery and variation of heating set-point (**solution 2**) is suggested in order to lower back heating need. This solution with an investment of around 243,000 €, joined with the previous solution, offered 50% of primary energy savings for the building. The implementation of solution 2 (measures 1b+2) would have a payback of 3.89 years.

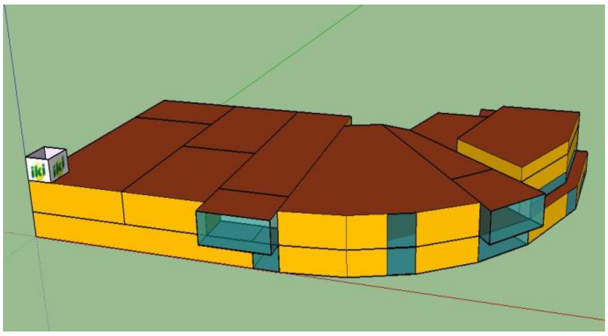
Finally, the introduction of RES will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. For this building it would be possible to install PV systems on the roof and wind turbines (**solutions 3a and 3b**). Firstly, the study of PV system with an estimated investment of near 171,000 € (1,500 m²), joined with the previous solutions, offered 63% of primary energy savings. The implementation of solution 3a would have a payback of 6.29 years. If we introduce wind power in order to exploit more the local generation (**solution 3b**), the study concluded that, with an estimated investment of 450.000 € for a 150 kW wind turbine, joined with the previous solutions, offered 69% of primary energy savings. The addition of solution 3b would have a payback of 24 years. Since the objective was to work with ROIs less than 7 years, this solution had to be neglected and the study stopped here.

Studlendas (Klaipeda - Lithuania)

Building model: input data summary

General data	
Gross floor area [m²]	12,637
Number of opening hours per day [h/d]	12
Number of opening days per week [d/w]	6

Thermal zone model



Number of thermal zones	17
First floor height [m]	4.48
Second floor height [m]	5.52

Zone typology	Zone group area [m²]
Shops	6,277.73
Technical rooms	1,129.73
Common areas	1,584.02
Offices	1,763.11
Restaurant	383.88
Gym	1,637.6
Services	368.16

Building envelope

Opaque envelope components	U-value [W/m²K]	
Exterior walls	0.105	
Roof	0.183	
Ground floor	0.484	
Glazed envelope components	**Ug [W/m²K]**	**g-value [-]**
Exterior window	1.06	0.626

	Common areas		Shops		Restaurant		Technical rooms		Offices		Gym		Services	
	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule
People density [pers/m²]	0.2	See graph on the right	0.2	8:00 – 21:00	0.25	See graph on the right	0	-	0.15	See graph on the right	0.25	8:00 – 21:00	0	-
Lighting density [W/m²]	23.7	8:00 – 21:00	36.2	8:00 – 21:00	28.2	8:00 – 21:00	0	-	23.9	8:00 – 21:00	30	8:00 – 21:00	0	-
Electric equipment [W/m²]	0	-	10	8:00 – 21:00	10	0:00 – 24:00	5	8:00 – 21:00	0	-	0	-	5	8:00 – 21:00
Heating setpoint temperature [°C]	21	8:00 – 21:00	21	8:00 – 21:00	21	8:00 – 21:00	-	-	21	8:00 – 21:00	21	8:00 – 21:00	21	8:00 – 21:00
Cooling setpoint temperature [°C]	25	8:00 – 21:00	25	8:00 – 21:00	25	8:00 – 21:00	-	-	25	8:00 – 21:00	25	8:00 – 21:00	-	-
Ventilation rates [kg/hr·m²]	7.35	8:00 – 21:00	7.35	8:00 – 21:00	14.7	8:00 – 21:00	3.02	8:00 – 21:00	7.35	8:00 – 21:00	7.35	8:00 – 21:00	11.02	8:00 – 21:00
Infiltration rates [ach]	0.55	0:00 – 24:00	0.55	0:00 – 24:00	0.55	0:00 – 24:00	0.55	0:00 – 24:00	0.55	0:00 – 24:00	0.55	0:00 – 24:00	0.55	0:00 – 24:00

HVAC systems control and efficiency

Energy demand for space heating and hot water is supplied by a district heating power plant which is next to the Shopping centre.
Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time.
No information about the HVAC and refrigeration plant layout of the supermarket are available.

Heating and cooling:

It has been assumed no cooling needs (No information). Almost constant electrical profile during the whole year with a little increase in summer (could be for the ventilation) and external temperatures are below 26ºC during almost the whole year.

Ventilation:

To maintain the temperatures in summer it has been assumed free cooling from middle of May (3,150h) to middle of September (6,300h). The schedule is from 00:00 to 8:00, with 8 renovations/hour. During this period has been also increased the ventilation values to 4.
It has been assumed a heat recovery from middle of September (6,300h) to middle of May (3,150h), with a performance of 55%.

Simulation settings

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time. The time step is set to 15 min and a preconditioning period of a month is considered.
Two weather files are used for the analysis:

- **Typical Meteorological Year (TMY)**, which derives from Meteonorm database (Meteotest, 2015) and is representative of the standard weather conditions.

- **Actual Metereological Year (AMY)**, which derives from Weather Analytics database (Weather analytics, 2015) and reports the actual weather conditions over 2013.

Actual building energy consumption

Electricity profile

Figure 212 shows a comparison between real electricity consumption in 2013 and simulation results.

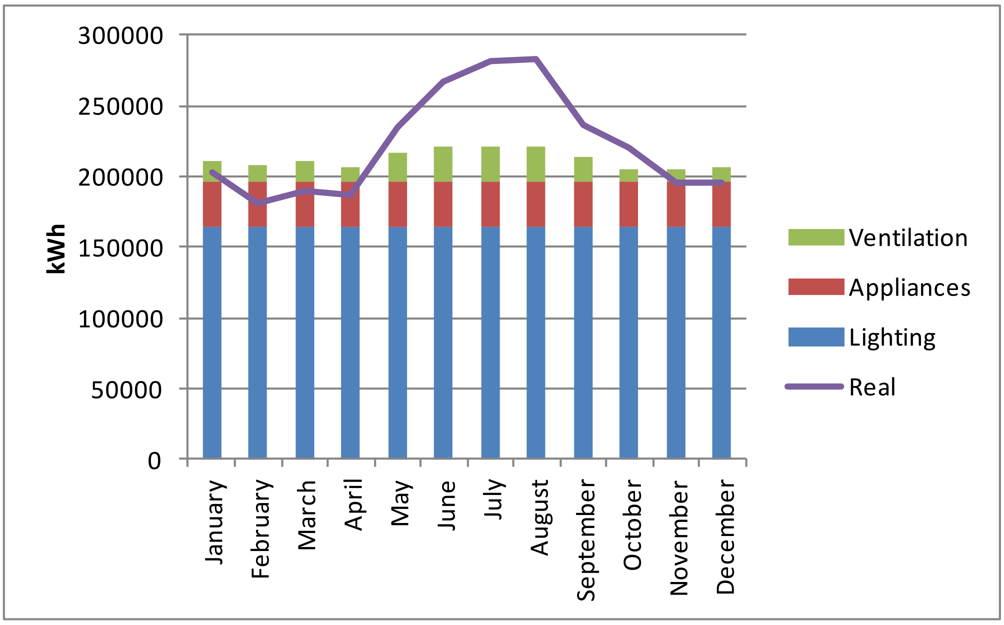


Figure 212. Real electricity consumption of the building for 2013 VS simulation results.

All the electricity consumption is due to lighting, ventilation and auxiliaries, not influencing the cooling (assuming no cooling needs) and heating (district heating).

The values of the indicators after the calibration are reported in Table 47.

Table 47. Tolerances values summary.

Type of consumption	Indicator	Tolerance (%)	Target tolerance (%)
Electricity	CVRMSE	11.294	<15
	NMBE	3.4938	<5

Heating profile

Figure 213 shows the comparison between the real heating consumption in 2013 and the simulation results. Values in summer months have been assumed only as part of DWH. In the rest of the months out of summer a similar value for DHW has been assumed as part of DHW.

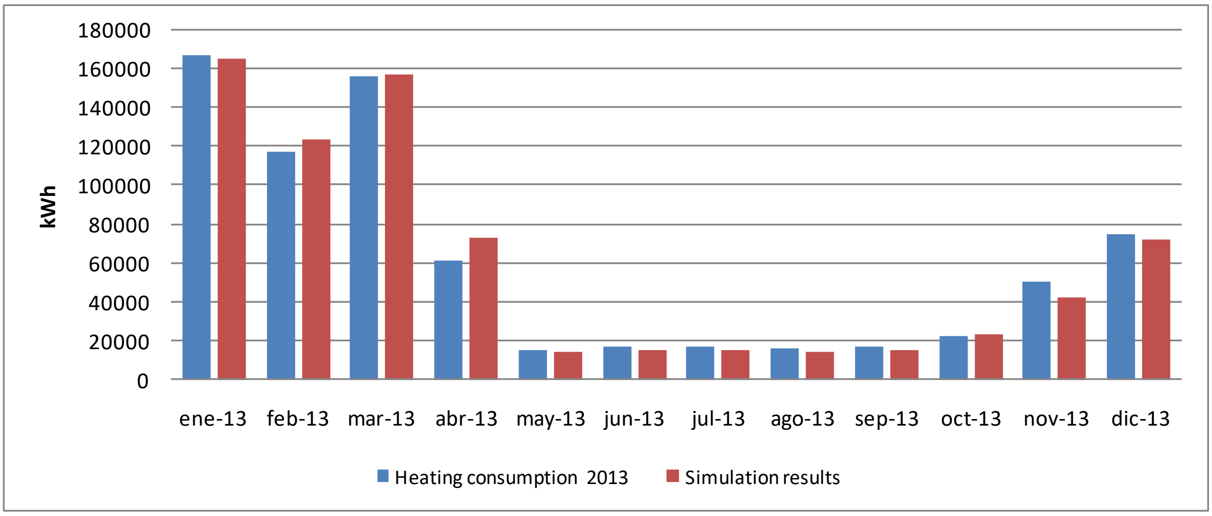


Figure 213. Comparison between real data consumption for heating in 2013 and simulation results.

The values of the indicators after the calibration are reported in Table 48.

Table 48. Tolerances values summary.

Type of consumption	Indicator	Tolerance (%)	Target tolerance (%)
Heating	CVRMSE	8.1572	<15
	NMBE	0.0071	<5

Electricity consumption

The graph in Figure 214 represents the electricity consumption divided by zone function.

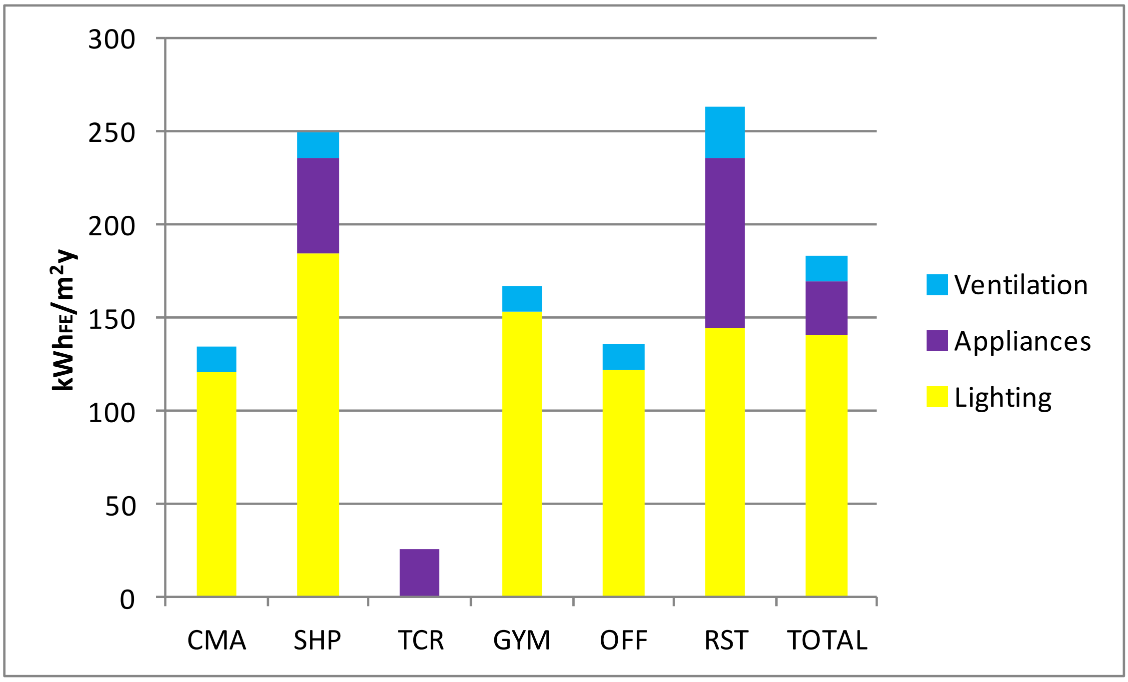


Figure 214. Electricity consumption for each group of zones: Common Areas (CMA), Shops (SHP), Technical room (TCR), Gymnasium (GYM), Offices (OFF), Restaurant (RST)

Solution sets description

One of the objectives of the CommONEnergy project is the development of architectural and energy systems retrofitting solution sets with the aim at reducing building energy needs, enhancing the overall energy efficiency to provide appropriate indoor environmental quality (IEQ) and exploiting renewable energy sources (RES).

By solution set we mean a combination of passive and efficient active measures, utility equipment and energy generation technologies. The measures are integrated looking for and exploiting synergies among HVAC, lighting, refrigeration, energy use as well as for building correlated services (parking, RES harvesting and local energy production etc.).

The solution set here described is balanced on the specific needs of Studlendas reference building and the climate conditions of Klaipeda.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decide to reduce lighting power density and to set-up a control strategy during the preparation hours, i.e. before the public opening of the building **(solution 1)**. Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need but increasing the heating demand.

The **solution 2** aims to reduce the heating demand that was increased after the reduction of lighting internal gains. This consists in improvements in the envelope, increase in the efficiency of the heat recovery and variations in the heating set points. In addition to the reduction in the heating demand, with the shadings on the south façade (restaurant area) it would be possible to reduce the amount of direct solar radiation entering in the building.

Finally, the installation of RES systems (PV + Wind Power) **(solution 3)** will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO_2 emissions.

Solution 1: Effective artificial lighting equipment + control strategies

Objective

To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off
With this solution is possible to reduce the electricity consumption of the building. By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have a higher impact on building energy consumption (this solution would be very interesting in combination with Solution 2).

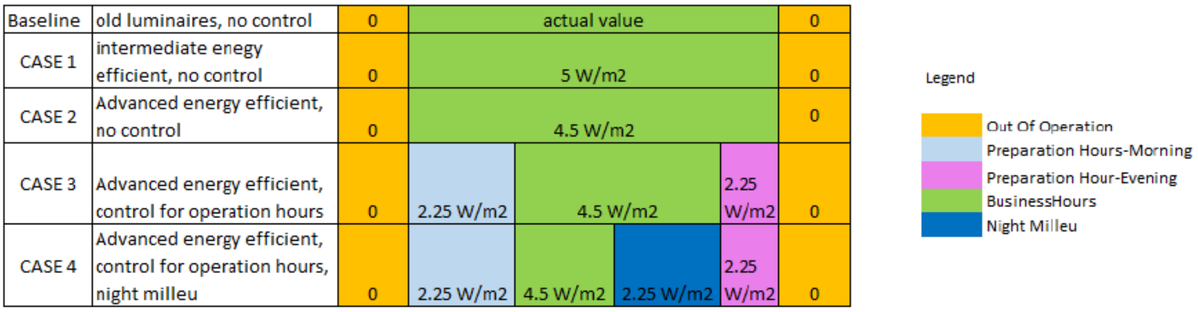
Description

Four different cases have been studied:

- Case 1: Intermediate energy efficient lighting with no control.
- Case 2: Advanced energy efficient lighting with no control.
- Case 3: Advanced energy efficient lighting with control for operation hours.
- Case 4: Advanced energy efficient lighting with control for operation hours and night milieu.

Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.

For common areas:

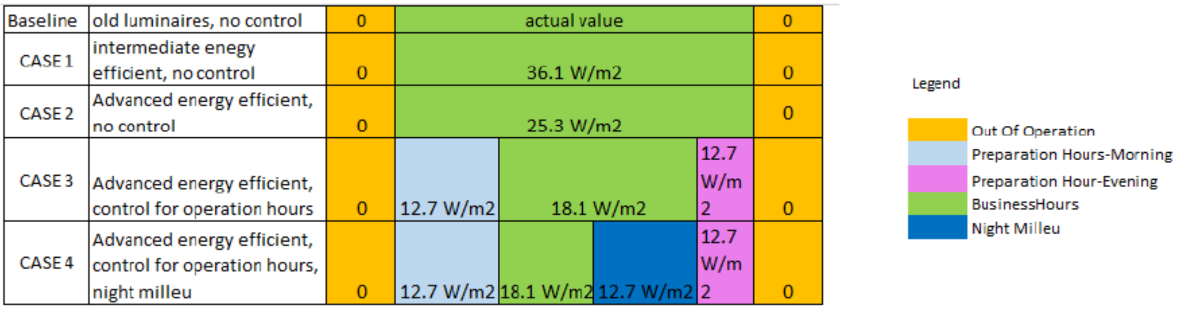


Baseline	old luminaires, no control	0	actual value				0
CASE 1	intermediate enegy efficient, no control	0	5 W/m2				0
CASE 2	Advanced energy efficient, no control	0	4.5 W/m2				0
CASE 3	Advanced energy efficient, control for operation hours	0	2.25 W/m2	4.5 W/m2		2.25 W/m2	0
CASE 4	Advanced energy efficient, control for operation hours, night milleu	0	2.25 W/m2	4.5 W/m2	2.25 W/m2	2.25 W/m2	0

Legend

🟨 Out Of Operation
🟦 Preparation Hours-Morning
🟪 Preparation Hour-Evening
🟩 BusinessHours
🟦 Night Milleu

For shops:

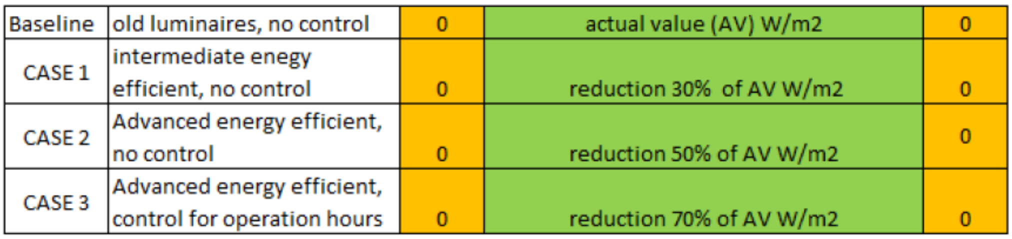


Baseline	old luminaires, no control	0	actual value				0
CASE 1	intermediate enegy efficient, no control	0	36.1 W/m2				0
CASE 2	Advanced energy efficient, no control	0	25.3 W/m2				0
CASE 3	Advanced energy efficient, control for operation hours	0	12.7 W/m2	18.1 W/m2		12.7 W/m2	0
CASE 4	Advanced energy efficient, control for operation hours, night milleu	0	12.7 W/m2	18.1 W/m2	12.7 W/m2	12.7 W/m2	0

Legend

🟨 Out Of Operation
🟦 Preparation Hours-Morning
🟪 Preparation Hour-Evening
🟩 BusinessHours
🟦 Night Milleu

For rest of areas:



Baseline	old luminaires, no control	0	actual value (AV) W/m2	0
CASE 1	intermediate enegy efficient, no control	0	reduction 30% of AV W/m2	0
CASE 2	Advanced energy efficient, no control	0	reduction 50% of AV W/m2	0
CASE 3	Advanced energy efficient, control for operation hours	0	reduction 70% of AV W/m2	0

Area of application

Artificial lighting of the whole shopping mall.

Expected energy savings

Case 1: 20% reduction in lighting consumption.
Case 2: 40% reduction in lighting consumption.
Case 3: 60% reduction in lighting consumption.

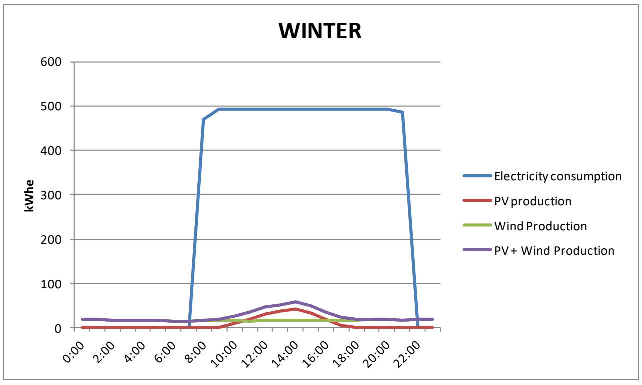
	Case 4: More than 60% reduction in lighting consumption.
Expected impact on comfort	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping centre.
Expected investment costs	LED lighting: 4 €/m² (min.price, standard product). LED lighting: 14 €/m² (max. price, dimable, A++ product).

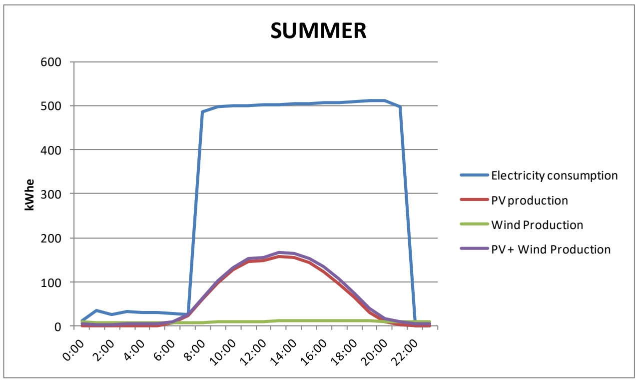
Solution 2: Energy efficiency measures
· Improvements in the envelope
· Heat recovery
· Variation of heating set point
· Shadings on the south façade (Restaurant area)

Objective	With this solution is possible to: • Reduce the heating demand of the building. • Reduce the amount of direct solar radiation entering in the building.
Description	Improvements in the envelope: After a parametric analysis of the insulation: Walls (From 25 cm to 30 cm), Roof (From 21 cm to 9 cm), and Floor (From 5 cm to 15 cm). Heat recovery: Increase in 5%. Variation of heating set point: Change the heating set point from 21ºC to 19ºC. Shadings on the south façade glazing: Change from 0% to 60%.
Area of application	Improvements in the envelope: Walls, Roof, Floor. Heat recovery: HVAC system. Variation of heating set point: Control of the HVAC system. Shadings on the south façade glazing: Restaurant area.
Expected energy savings	Reduction in more than 40% of heating demand in case of application together with Solution 1.
Expected impact on comfort	Improve the comfort during the occupied hours. Softening discomfort due to overheating especially in summer and mid-season period
Expected investment costs	Improvements in the envelope: Insulation cost 100 €/m³ Heat recovery: 6.2 €/m³h Variation of heating set point: No investment cost; it is just based on changing controls. Shadings on the south façade: 90 €/m²

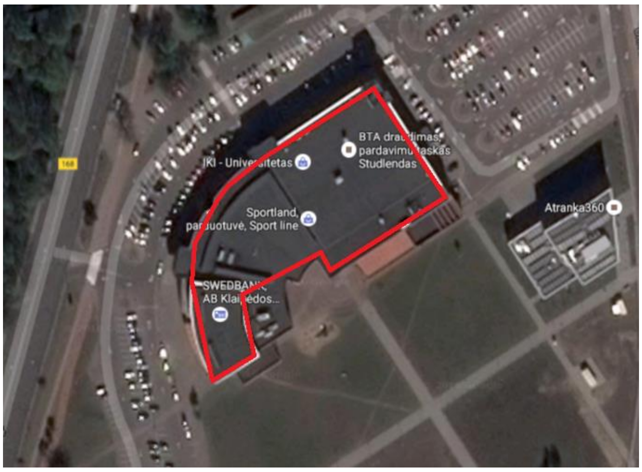
Solution 3: RES integration (PV panels + Wind turbine)

Objective	On site RES are a good solutions to produce electricity increasing the self-consumption and self-production and thus reduce the amount extracted from the grid.
Description	Good weather conditions for the intregration of RES systems, located in the outskirts of Klaipeda without obstacles and with surface available on the roof (total roof area: 3,000 m²), The photovoltaic generation profile is suitable for the demand profile of the building because the photovoltaic generation peaks coincide with the market demand peaks. It is possible to install a medium-size (150 kW) wind turbine system, due to the climatologic conditions (wind speed ~ 5 – 6 m/s) and without buildings surrounding the shopping mall.





Load profiles will change due to other solutions.



Area of application	Roof
Expected energy Production	The yearly simulation performed give us the following energy production estimation: Wind Power: 94,000 kWh/y Photovoltaic: 315,374 kWh/y
Expected investment costs	PV system: 1,000 €/kW Wind turbine: 3,000 €/kW

Results

Energy and operative costs savings

The graph in Figure 215 shows the actual yearly final energy consumption of the baseline model and the potential energy savings of the energy efficiency measures described before.

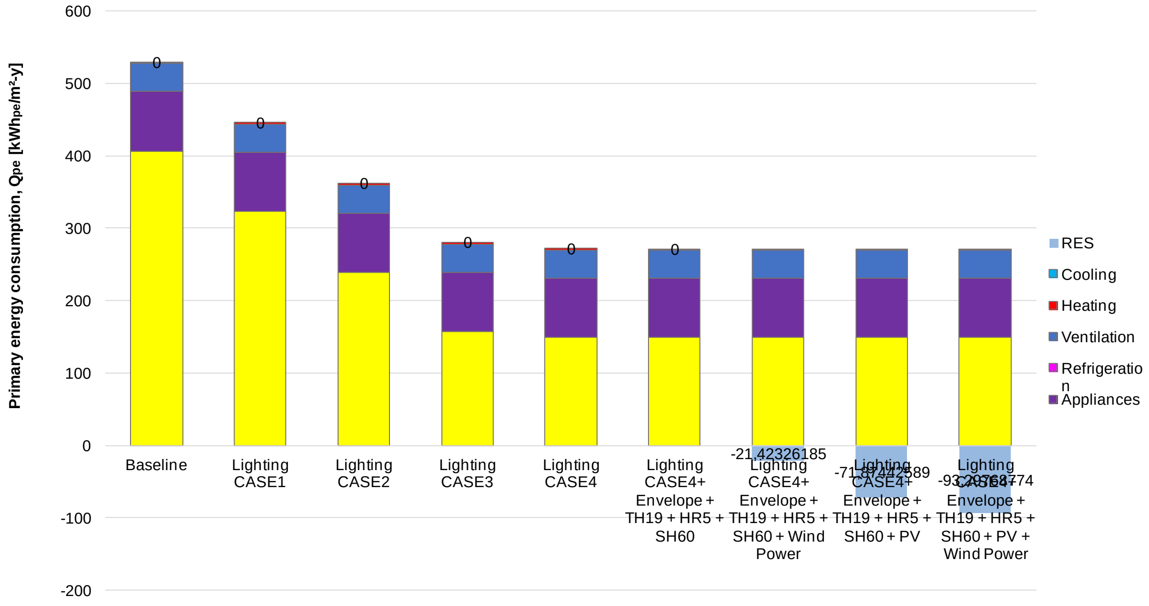


Figure 215. Yearly final energy consumption.

Economic analysis

The economic analysis is based on the assumptions listed in Table 49.

Table 49. Economic analysis assumptions

Assumptions	Value
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	5.08%
Energy costs	
Cost of electricity	0,1324 €/kWh
Cost of district heating	0.05797 €/kWh
Electricity buy price annual variation	3%/year
Electricity sell price annual variation	3%/year
Installation ageing	0.5%/year
Insurance	
Insurance	0.5% for PV 0.3% for WP
Taxes	15%
Maintenance	2.5% for PV

	4% for WP
Contingency	5% from previous concepts
Annual variation	0.5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**.
The results of the cash inflows and outflows is shown over the 25 years period studied are shown in the graphs in Figure 216 to Figure 220.

Solutions		Description
1a	**Lighting**	LED standard product

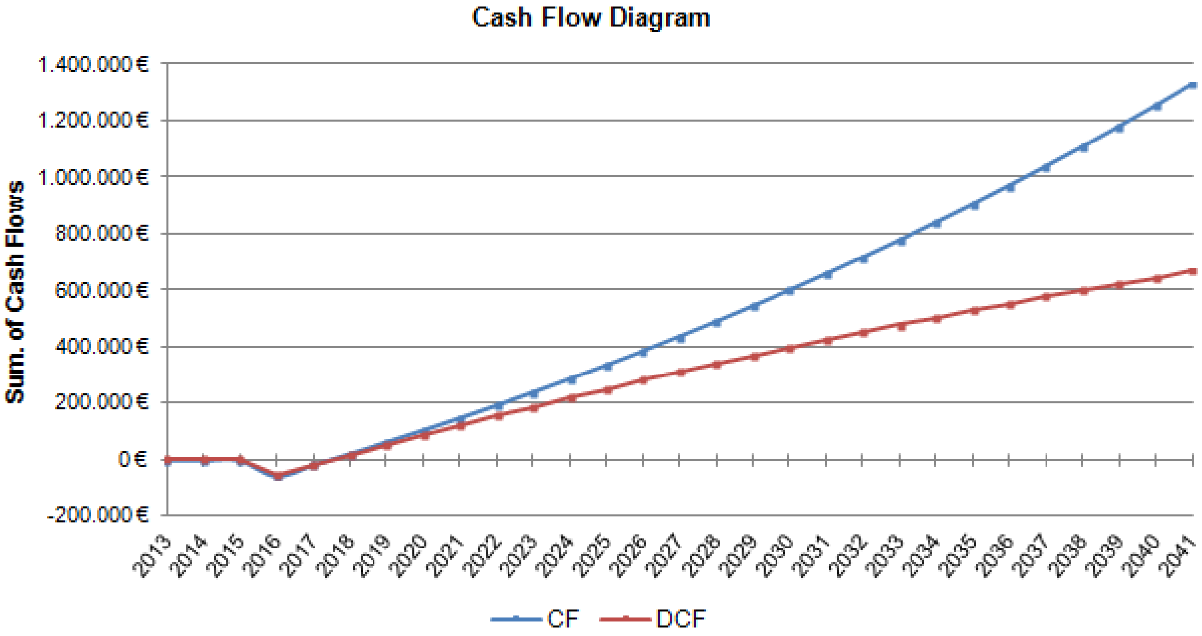


Figure 216. Cash flow diagram S1a

The installation of standard (LED) would have a ROI period of 1.51 years.

Solutions		Description
1a	**Lighting**	LED standard product
1b	**Lighting**	LED dimable, A++ product

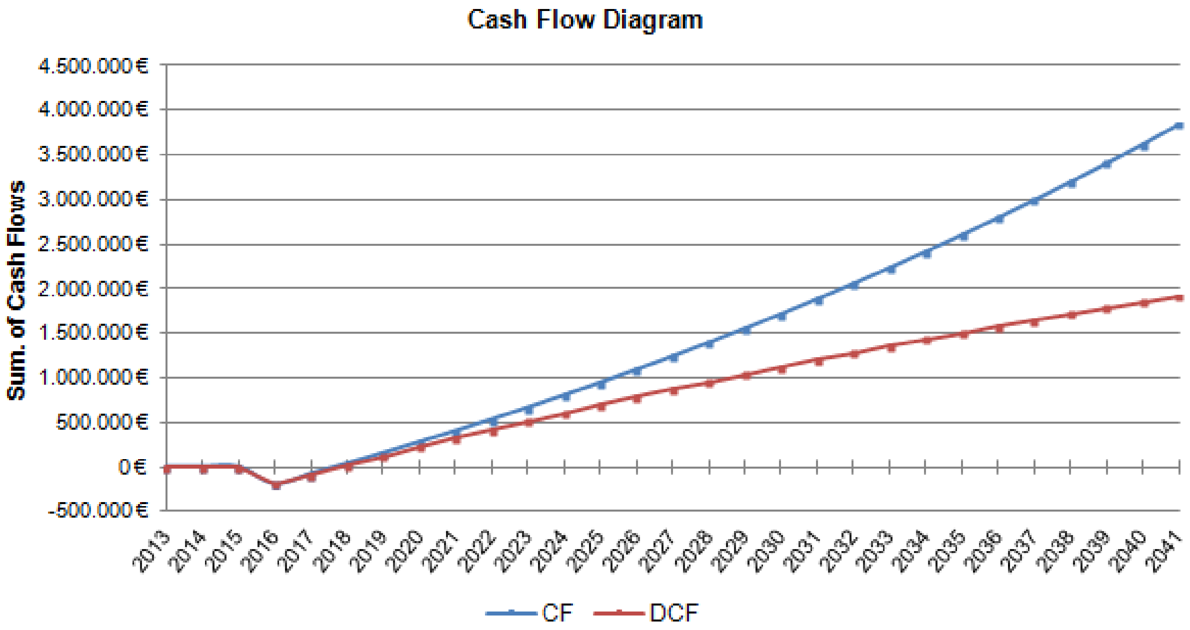


Figure 217. Cash flow diagram S1b

The installation of efficient lighting (LED) with better control strategy would have a ROI period of less than 1.83 year.

Solutions		Description
1a	**Lighting**	LED standard product
1b	**Lighting**	LED dimable, A++ product
2	**Energy efficiency measures**	Improvements in the envelope Heat recovery Variation of heating set point Shadings on the south façade (Restaurant area)

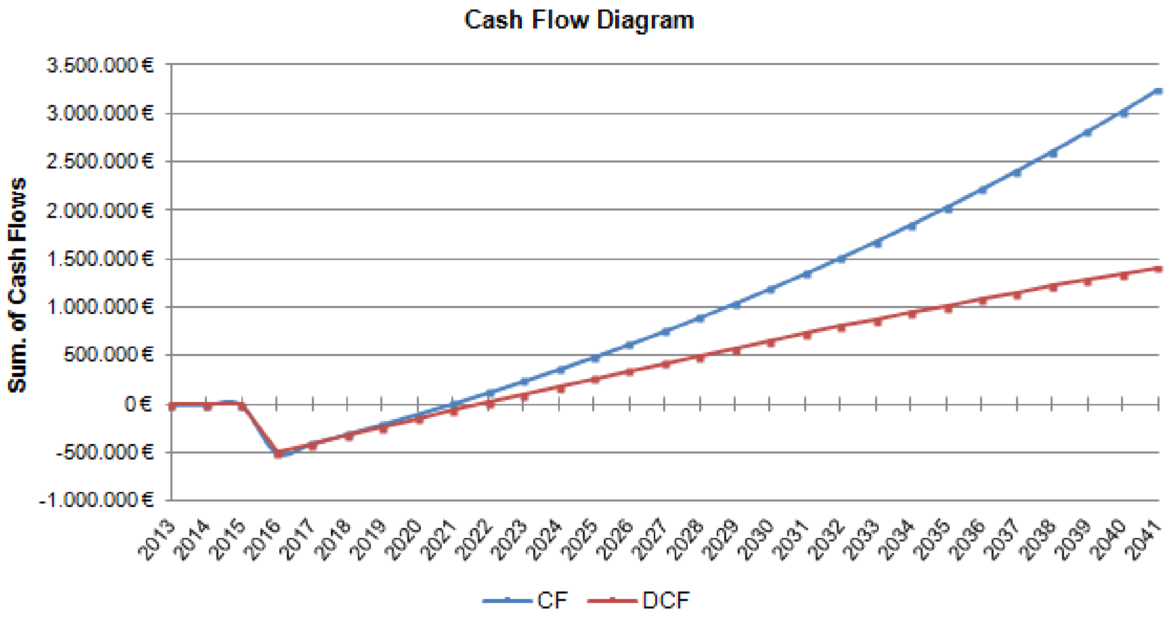


Figure 218. Cash flow diagram S1b-2

The installation of efficient lighting (LED) with better control strategy, addition of energy efficiency measures would have a ROI period of 5.72 years.

Solutions		Description
1a	**Lighting**	LED standard product
1b	**Lighting**	LED dimable, A++ product
2	**Energy efficiency measures**	Improvements in the envelope Heat recovery Variation of heating set point Shadings on the south façade (Restaurant area)
3a	**RES**	PV

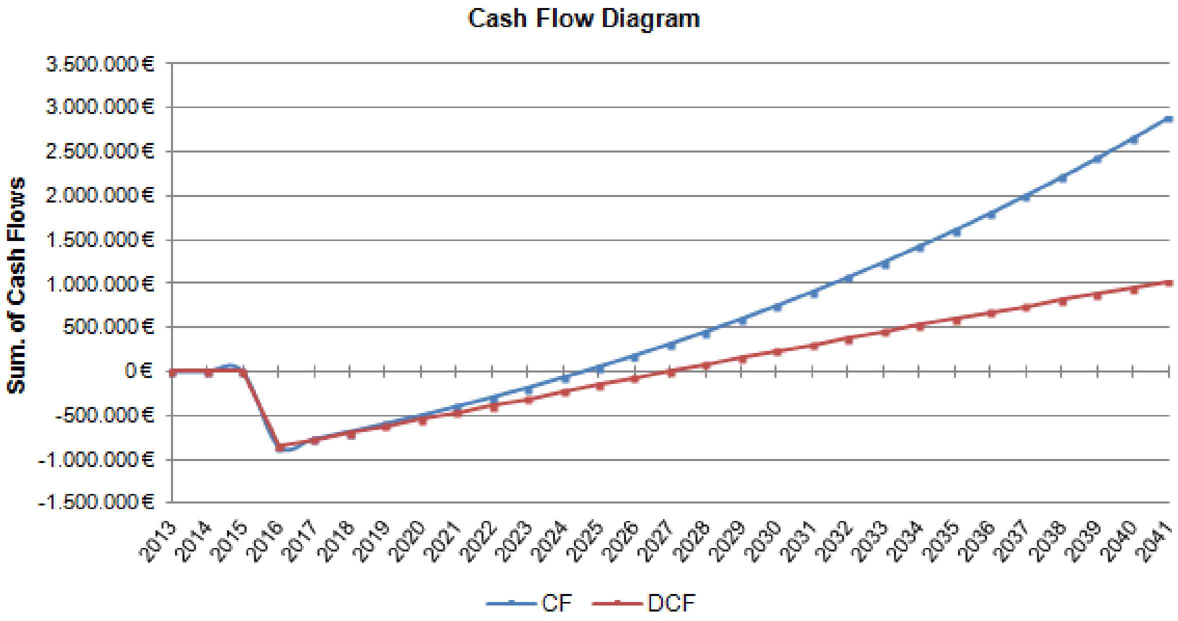


Figure 219. Cash flow diagram S1b-2-3a

The installation of efficient lighting (LED) with better control strategy, addition of energy efficiency measures and PV would have a ROI period of 10.99 years → Out of scope (<7 years).

Solutions		Description
1a	**Lighting**	LED standard product
1b	**Lighting**	LED dimable, A++ product
2	**Energy efficiency measures**	Improvements in the envelope Heat recovery Variation of heating set point Shadings on the south façade (Restaurant area)
3a	**RES**	PV
3b	**RES**	Wind Power

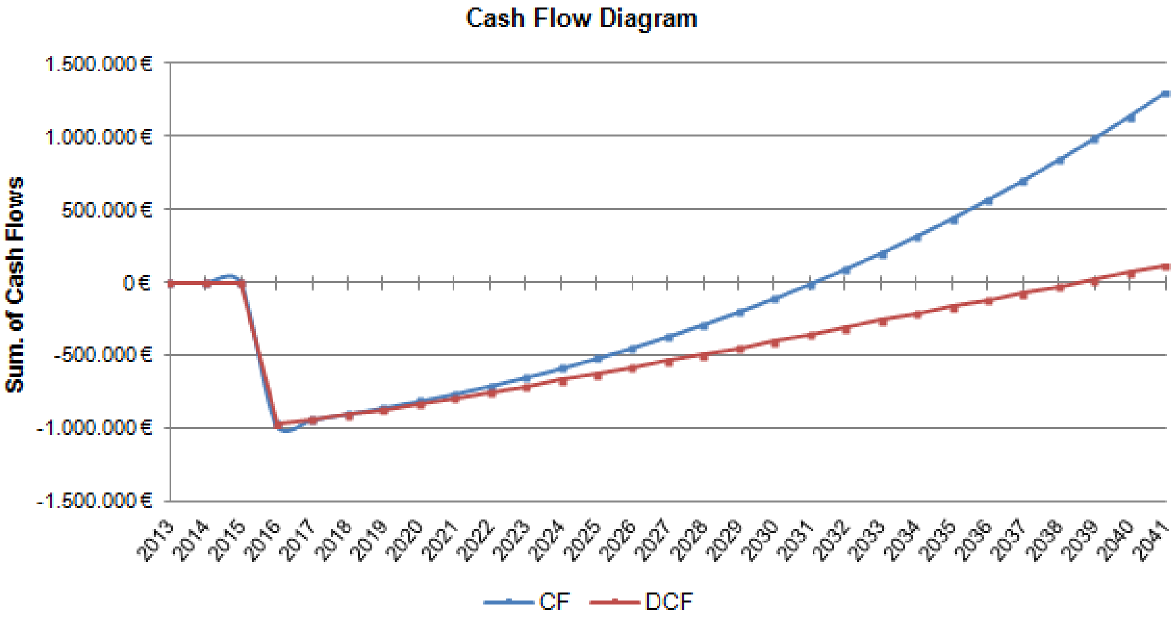


Figure 220. Cash flow diagram S1b-2-3b

The installation of efficient lighting (LED) with better control strategy, addition of energy efficiency measures and WP would have a ROI period of 22.47 years→ Out of scope (<7 years).

Conclusions

The energy simulation model of the Studlendas reference building has allowed us to predict energy consumption and test and quantify potential energy savings with different solutions. For the development of the energy simulation model has been used mainly real information coming from the reference building, but on the other hand, for some aspects in which the information has not been possible to be collected, has been needed to use some assumptions indicated within this document and which need to be cross checked.

After developing several simulations implementing both passive solutions (energy efficiency measures) and active solutions (artificial lighting and RES), we have obtained the conclusion that could have a great potential of improvement. With the energy efficiency measures here described, it would be possible to reduce in a high amount the heating demand of the building and thus the expenses due to the district heating. With the advanced artificial lighting systems it is possible to reduce in a high amount the electrical consumption and thus reduce the electricity bill. With the RES it is possible to cover part of the electricity demand of the building and in this way to reduce the electricity coming from the grid.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decided to reduce lighting power density **(solution 1)**. This solution with an investment of 184,000 € offered almost 49% of primary energy savings. The implementation of solution 1 would have a payback of 1.83 years.

Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need, but increasing the heating demand. Therefore, a complete retrofit with insulation layer, heat recovery, variation of heating set-point and shadings on the south façade (**solution 2**) is suggested in order to lower back heating need. This solution with an investment of around 286,400

€, joined with the previous solution, offered 50% of primary energy savings for the building. The implementation of solution 2 (measures 1b+2) would have a payback of 5.72 years.

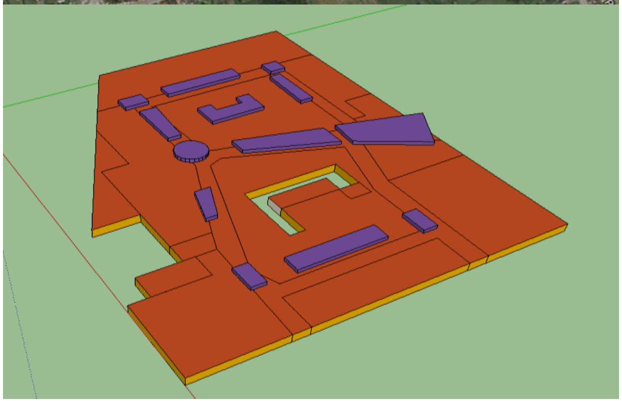
Finally, the introduction of RES will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. For this building it would be possible to install PV systems on the roof and wind turbines (**solutions 3a and 3b**). Firstly, the study of PV system with an estimated investment of near 344,000 € (3,000 m²), joined with the previous solutions, offered 62% of primary energy savings. The implementation of solution 3a would have a payback of 10.99 years. If we introduce wind power instead of PV in order to exploit other local generation solutions (**solution 3b**), the study concluded that, with an estimated investment of 450.000 € for a 150 kW wind turbine, joined with the previous solutions, offered 53% of primary energy savings. The addition of solution 3b would have a payback of 22 years. Since the objective was to work with ROIs less than 7 years, these two last solutions had to be neglected and the study stopped here.

Waasland (Sint Niklaas - Belgium)

Building model: input data summary

General data	
Gross floor area, [m²]	45315
Common areas and galleries [m²]	7934
Number of opening hours per day [h/d]	10
Number of opening days per week [d/w]	6

Thermal zone model



Number of thermal zones	16
Height [m]	7
Zone typology	Zone group area [m²]
Shops	29172
Restaurants	2258
Food store	3807
Warehouse	2143
Common areas	7934

Building envelope

Opaque envelope components	U-value [W/m²K]	Solar absorptance [-]
Exterior walls	1.16	
Adjacent walls	2.8	
Exterior roof	1.5	
Ground floor	1.3	
Glazed envelope components	Ug [W/m²K]	g-value [-]
Exterior windows	2.8	

	Common areas (CMA)		**Shops (SHP)**		**Warehouse (WRH)**		**Food store (FDS)**		**Restaurant (RST)**	
	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule
People density [pers/m²]	0.2	06:00 – 22:00	0.2	08:00 – 20:00	0.1	08:00 – 20:00	0.2	08:00 – 20:00	0.25	08:00 – 20:00
Lighting density [W/m²]	35	08:00 – 22:00	40	08:00 – 22:00	35	08:00 – 22:00	45	08:00 – 22:00	40	08:00 – 22:00
Electric equipment [W/m²]	10	00:00 – 24:00	10	00:00 – 24:00	10	00:00 – 24:00	20	-	15	00:00 – 24:00
Heating setpoint temperature [°C]	20	07:00 – 21:00	20	07:00 – 21:00	17	07:00 – 21:00	20	07:00 – 21:00	20	07:00 – 21:00
Heating setback temperature [°C]	-	21:00 – 07:00	-	21:00 – 07:00	-	21:00 – 07:00	-	21:00 – 07:00	-	21:00 – 07:00
Cooling setpoint temperature [°C]	23	09:00 – 20:00	23	09:00 – 20:00	25	09:00 – 20:00	23	09:00 – 20:00	23	09:00 – 20:00
Cooling setback temperature [°C]	-	-		-		-		-		-
Ventilation rates [ach]	0.8	09:00 – 19:00	0.8	09:00 – 19:00	0.8	09:00 – 19:00	0.8	09:00 – 19:00	0.8	09:00 – 19:00
	0.4	19:00 – 09:00	0.4	19:00 – 09:00	0.4	19:00 – 09:00	0.4	19:00 – 09:00	0.4	19:00 – 09:00
Infiltration rates [ach]	0	00:00 – 24:00	0	00:00 – 24:00	0	00:00 – 24:00	0	00:00 – 24:00	0	00:00 – 24:00

HVAC systems control and efficiency

In the building, two gas boilers with 1400 kWth are installed (generally only one is working) and 10 air-to-water heat pumps are installed (Using air to dissipate heat/cool energy, and water to distribute the energy (heat/cool). There is not any heat recovery system.

We considered the following efficiencies to estimate the electricity consumption:

- Gas boiler eff: 0.9
- Air-to-water heat pump EER: 2.5

The heating demand of the mall has been calculated by imposing a set point temperature of 20°C from 7 am to 9 pm being disconnected during night. The cooling demand has been calculated by imposing a set point temperature of 23°C from 7 am to 9 pm. The cooling system is turned off during the night. No additional air humidification is considered during the winter time.

The heating and cooling system are shut off on Sunday and closing days.

Simulation settings

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

One weather file is used for the analysis representing the **Actual Metereological Year (AMY)**, which derives from Weather Analytics database (Weather analytics, 2015) and reports the actual weather conditions over 2014.

Actual building energy consumption

Calibration

The model is calibrated on the basis of monthly electricity consumption of common areas provided by bills in 2014. Since no monitored data are available from tenants, the shops, restaurants, warehouses and food store zone models cannot be calibrated. The model calibration has been performed using the weather file provided by Weather Analytics representing the actual meteorological year (AMY) of 2014 in Sint-Nikklas.

Figure 221 and Figure 222 show a comparison of the predicted and measured electricity and gas consumption.

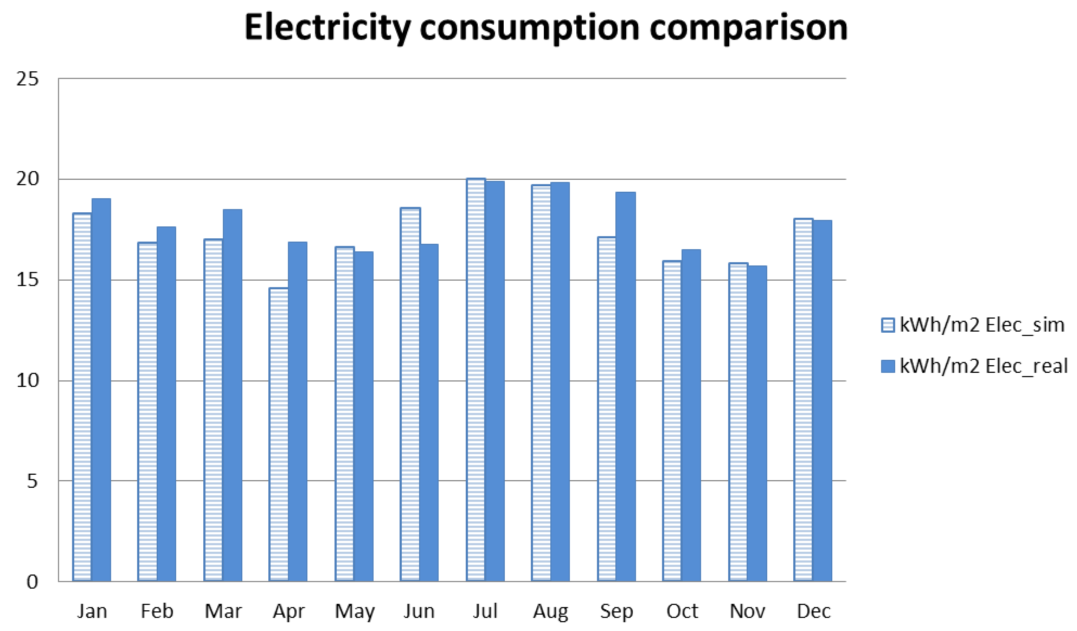


Figure 221. Predicted monthly electricity consumption compared to the electricity bills

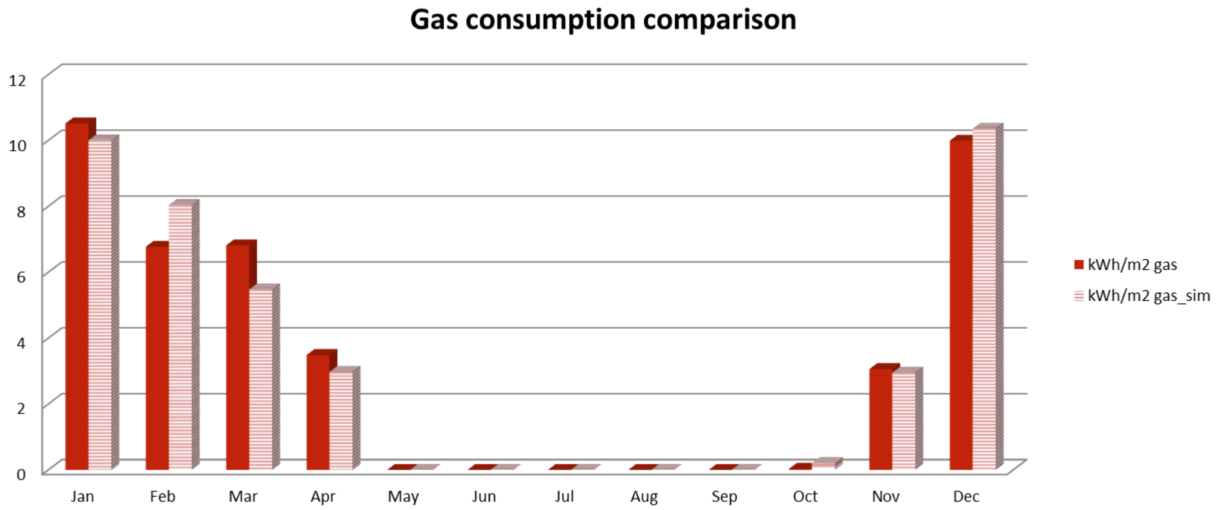


Figure 222. Predicted monthly gas consumption compared to the gas bills

Electricity consumption

The graphs in Figure 223 and Figure 224 represents the electricity consumption in the common area and the general building. It can be seen that the highest electricity consumption is due to the high lighting power density.

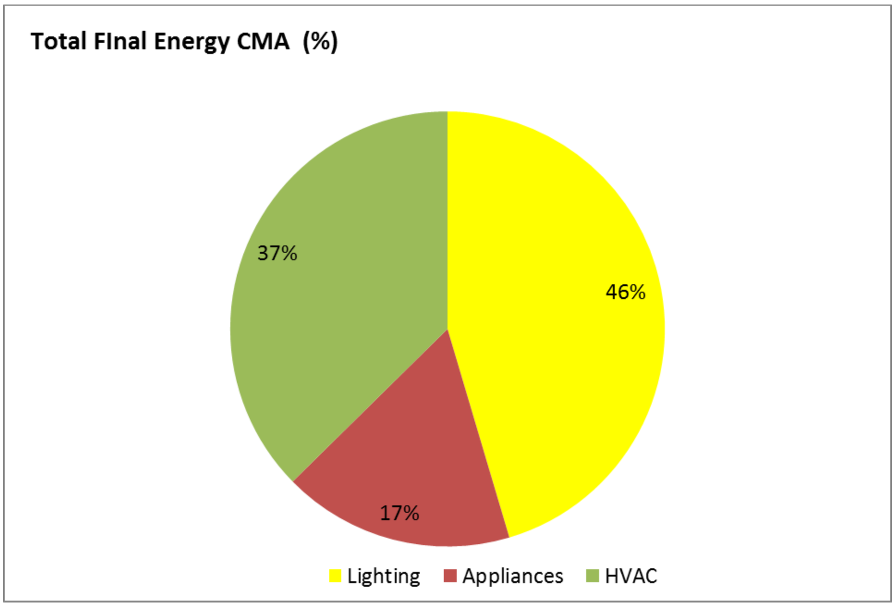


Figure 223. Electricity consumption percentage for Common Areas (CMA)

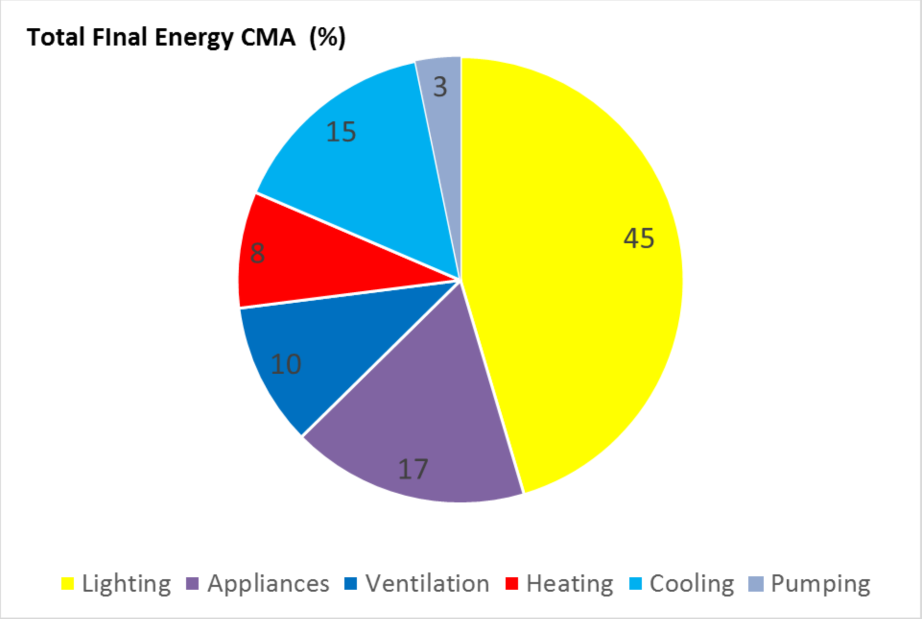


Figure 224. Electricity consumption percentage for Common Areas (CMA).

Total electricity consumption simulated for the common areas amounts at 2334 MWh/y which corresponds to 294 kWh/m²-y considering the conditioned area of 7934 m².

In the case of the general shopping mall (Figure 225), the results are proportionally similar.

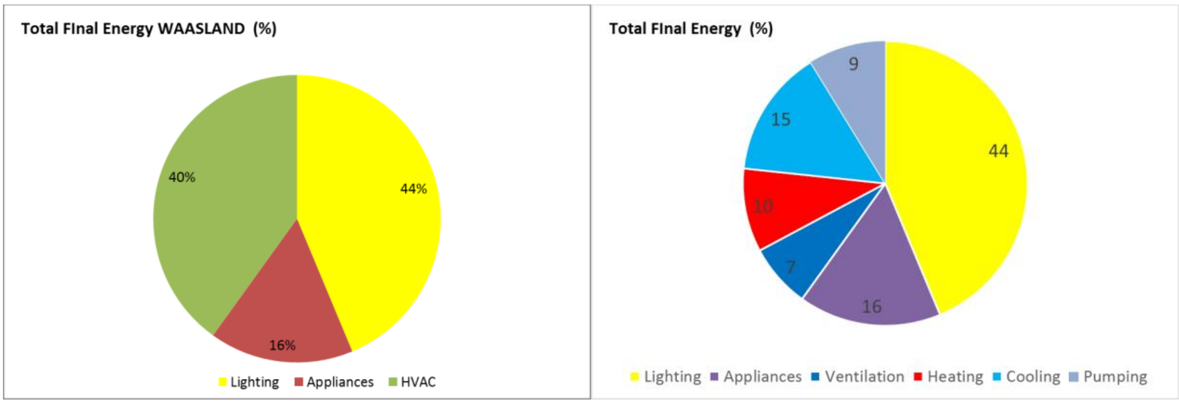


Figure 225. Electricity consumption percentage for the whole shopping mall

Solution sets description

The solution set here described is balanced on the specific needs of the Waasland building and the climate conditions of Sint-Nikklas. Therefore, its replication in other climates or other buildings need to be further investigated.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decide to reduce lighting power density **(solution 1)**. Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need, but increasing the heating demand. Therefore, a complete retrofit with insulation layer (**solution 2**) is suggested in order to lower back heating need and reduce further cooling need. In a further step the green vegetation in the form of foliage fixed with wiring on the external side of the wall was added. That is aimed to improve the wall shading during summer time for decrease of heat originated from solar irradiation, to introduce microclimate effects and to enhance the visual comfort for clients (**solution 3**).

The installation of energy efficient appliances is seen as an important further step to reduce energy use in the shopping centre (**solution 4**).

The following step done deals with the integration of a new system for heat recovery purpose, since in the building there is not any equipment to recover and save energy from the existing system (**solution 5**).

Finally, the installation of RES **(solution 6)** will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. For this building it would be possible to install PV systems on the ground (over the parking) with or without electrical storage or other kind of renewable system such as biomass boiler (**solution 7**).

Each solution is described in more details in the following pages.

Table 50. Summary of solutions

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Insulation**	External walls, roof and ground floor with better U-value in order to improve thermal losses
3	**Green integration**	SE external vegetable walls
4	**Appliances**	Energy efficient appliances, escalators etc.
5	**Heat recovery**	Heat recovery equipment integration

6.1	**RES – PV**	Photovoltaic panels on the ground
6.2	**RES – PV + Batteries**	Photovoltaic panels on the ground + Electrical storage
7	**RES – Biomass**	Biomass boiler for heating needs

Solution 1: Efficient lighting system and controls

Objective	To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off
Description	Lighting power density is reduced down to 10 W/m^2 in the common areas and galleries and to 70% in the other areas (shops, restaurants, food store) because of the installation of LED lamps. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.
Area of application	Common areas, shops, midsize stores, food store
Energy savings	55% reduction of electricity consumption due to lighting 85% cooling need reduction
Expected impact on comfort	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall.
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have an impact on building energy consumption.
Expected investment costs	LED lighting: 4 €/m^2 (min.price, standard product). LED lighting: 14 €/m^2 (max. price, dimable, A++ product).

Solution 2: High insulation

Objective	To reduce heating need by insulating the roof, external walls and ground floor
Description	Additional insulation layer is added to the roof, ground and external walls, in order to achieve a U-value of 0.67. External wall→ 2.5 cm fiberglass insulation Roof → 2.5 cm fiberglass insulation Ground floor -- 3 cm fiberglass insulation Additionally, green integration would smooth the temperature in the external layer of the walls.
Area of application	Roof, external walls and ground floor
Expected energy savings	12% reduction of heating needs (roof + external walls) 36% reduction of heating needs (roof + external walls + ground)
Expected impact on comfort	Softening of comfort conditions.
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and therefore the heating demand of the building increases, therefore, the addition of insulation will decrease the heating demand.
Expected investment costs	Around 150 €/m^3

Solution 3: Green integration

Objective	Improve the effective thermal resistance of the external wall
Description	Exterior wall covered with climbing vegetation. 1576.19 m² of vegetation on the SE external walls. A plant layer added to the facade can improve its effective thermal resistance by 0.0–0.7 m² K/W, depending on a range of inputs for wall parameters, climate zones, and plant characteristics (particularly leaf area index).
Area of application	External wall with SE orientation; possible extension to walls facing E and W.
Expected energy savings	1% of cooling energy demand; optionally up to 2,5%, when E and W walls will be covered with foliage (1400 m²)
Expected impact on comfort	Improvement of microclimate in the neighbourhood of shopping centre building by humidity and dust PMs. Improved rainfall water management.
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and therefore the heating demand of the building increases, therefore, the addition of green integration on the external walls will decrease the cooling demand.
Expected investment costs	Depending on different boundary conditions, it varies between 75 and 130 €/m² and 20.000 €/year for maintenance.

Solution 4: Appliances

Objective	To reduce energy consumption for appliances by exploiting existing systems.
Description	Appliances in shopping centres consist of • Distribution Transformers • IT Equipment (non-data centre) • Water Treatment/Distribution • PCs (Laptops, Desktops, Monitors) • Cash machines • Kitchen Equipment (in restaurants) • Refrigerators/Freezers (in supermarkets) • Video Displays/Boards • Security Systems • Vending machine • Escalators • Elevators • Security lighting The appliances will be exchanged in maintenance cycles with high efficiency products. It is assumed a reduction of 50% of the energy consumption ratios used as baseline.
Area of application	Common areas, shops, food store, restaurants, warehouse
Expected energy savings	4% electricity consumption
Expected impact on comfort	The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.
Interaction with other solutions	The reduced internal heat gains will reduce cooling demand and increase heating demand.
Expected investment costs	To be determined.

Solution 5: Heat recovery system

Objective	Reduce thermal consumption of the building
Description	Integration of heat recovery system to the existing installations with 50% of efficiency.
Area of application	General building.
Expected energy savings	25% reduction of heating consumption (final energy) by the thermal installation. Thermal demand of the building will be the same, however, with heat recovery system the final consumption will be lower.
Expected impact on comfort	No impact.
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and therefore the heating demand of the building increases, therefore, the integration of the heat recovery system will improve the thermal consumption of the equipment (with the consequent economic benefits).
Expected investment costs	Around 6.3 €/m³/h

Solution 6.1: Photovoltaic plant

Objective	Installation of PV plant on the parking-ground to increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO_2 emissions.
Description	The only PV plant can improve the “green-energy” produced on-site and decrease the energy imported from the grid. 4600 m^2 of polichristaline PV panels have been used for the study with a local generation potential coverage of 50% (focused on lighting and appliances electricity consumption). It is interesting to define the 4 external available areas. • Parking-Roof: Existing area in the roof building used as parking for Waasland clients. Considering their external characteristics, it´s a good area to install pergolas to cover the vehicles and use it to install some renewable system, like photovoltaic modules. • Parking-Ground: Similar area used as parking for Waasland clients, but in this occasion situated at ground level. It´s possible to consider the installation of pergolas covering the vehicles and at the same time to use these pergolas to install photovoltaic modules. • Roof: Partially area used to the installation of energy systems and ventilation ducts. The rest free roof area has many possibilities to install new energy technologies or passive elements to reduce the energy demand. • Covers: Other areas with possibilities to be used on the roof building. The covers will be used to install active systems to generate thermal or electric energy. •
Area of application	Parking-Ground
Expected energy savings	With this solution part of the electrical consumption can be covered combined with a self-electricity production with enclosed CO2 emissions reduction (35% of demand coverage by RES with 4600 m^2 of panels used.)
Expected impact on comfort	No impact on thermal comfort since it will be potentially installed on the parking area roof
Interaction with other solutions	On-site electricity production can cover part of the lighting and appliances electrical consumption
Expected investment costs	Around 1500 €/kWp and 10% for engineering/permitting, 10% for construction/installation

Solution 6.2: Photovoltaic plant + Batteries

Objective	Installation of PV plant + batteries on the parking-ground to increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO_2 emissions.
Description	The only PV plant can improve the “green-energy” produced on-site and decrease the energy imported from the grid. If the PV is combined with a battery energy storage system, advantageous situation are for suppling a dedicated load (e.g. lighting system) or shave the peak (only to smooth the energy profile and not strictly related to the energy prices during the day). 4600 m^2 of polichristaline PV panels and a set of electrical storage batteries (with 500 kW of capacity and 2000 kWh of energy storage) have been used for the calculation with a local generation potential coverage of 50% (focused on lighting and appliances electricity consumption).
Area of application	Parking-Ground
Expected energy savings	With this solution part of the electrical consumption can be covered combined with a self-electricity production with enclosed CO2 emissions reduction (46% of demand coverage by RES with 4600 m^2 PV panels and 2000 kWh of electrical storage.)
Expected impact on comfort	No impact on thermal comfort since it will be potentially installed on the parking area roof
Interaction with other solutions	On-site electricity production can cover part of the lighting and appliances electrical consumption
Expected investment costs	Around 1500 €/kWp for PV and 700 €/kWh for batteries. 10% for engineering/permitting, 10% for construction/installation

Solution 6.3: Biomass boiler

Objective	Installation of biomass boiler in order to decrease the energy imported from other pollutants fuels and the CO_2 emissions.
Description	Since currently the building uses a gas boiler for heating needs, its replacement by a biomass boiler is proposed.
Area of application	General building
Expected energy savings	Using a biomass boiler with higher efficiency than the existing one, a reduction of consumption for heat production would be achieved with enclosed CO2 emissions reduction.
Expected impact on comfort	No impact on thermal comfort but only energy savings
Interaction with other solutions	No interaction
Expected investment costs	Around 900 €/kW

Results

Following, the results obtained after performing the simulation activity and energy/cost balance analysis for the different measures proposed.

Energy and operative costs savings

The graph in Figure 226 shows the actual yearly primary energy consumption of the baseline model for the overall shopping mall and the potential energy savings of the energy efficiency measures described in par.0. Total costs refers to the operative costs due to the price of electricity, gas or biomass.

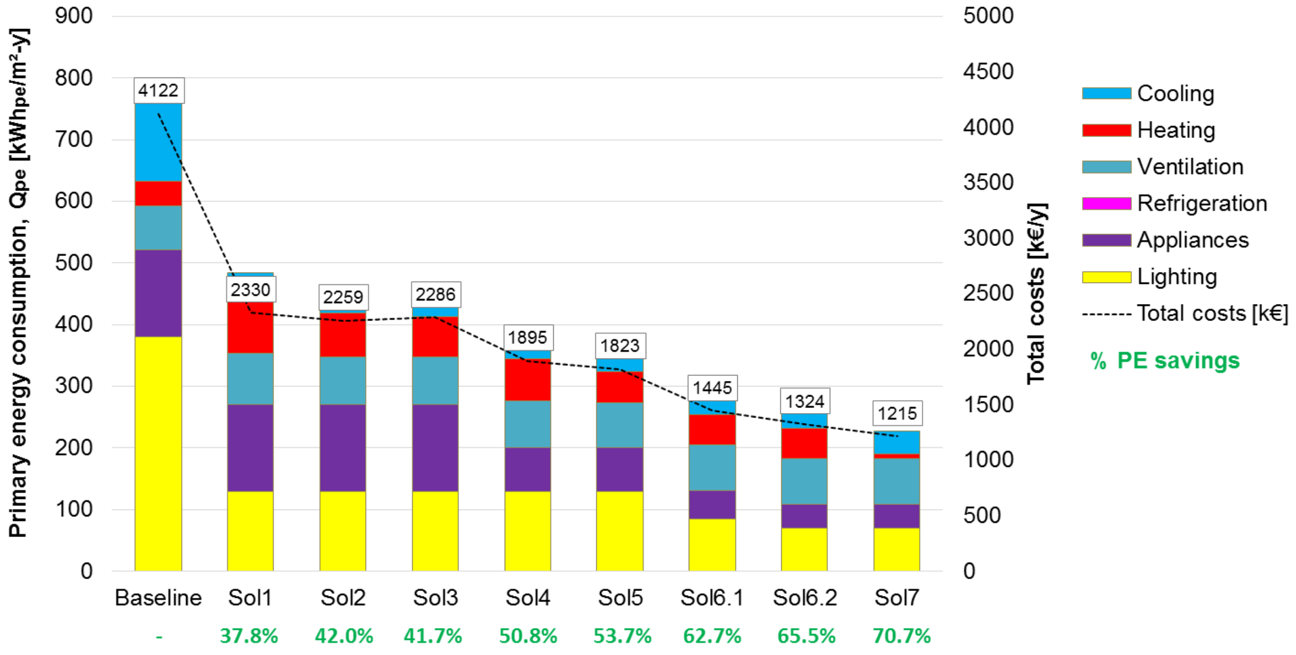


Figure 226. Yearly primary energy consumption and operative costs in Waasland shopping centre.

The graph in Figure 227 shows the actual yearly final energy consumption of the baseline model for the common areas and the potential energy savings of the energy efficiency measures described previously. Total costs refers to the operative costs due to the price of electricity, gas or biomass.

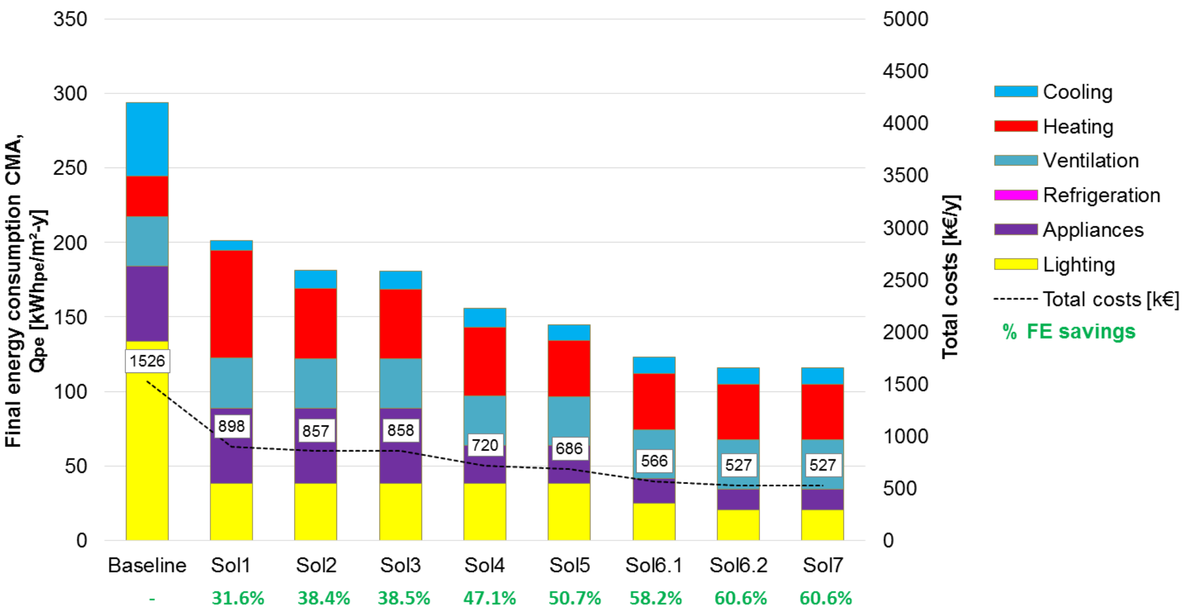


Figure 227. Yearly Final energy consumption and operative costs in common areas WSc.

Economic analysis

The economic analysis is based on the assumptions listed in Table 51.

Table 51. Economic analysis assumptions

Assumptions	Value
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	3,54%
Energy costs	
Cost of gas	0.055 €/kWh
Cost of electricity (buy)	0.17 €/kWh
Cost of electricity (sell)	0.10 €/kWh
Electricity buy price annual variation	3,54%/year
Electricity sell price annual variation	3,54%/year
Installation ageing	0,5%/year
Operation costs	
Insurance	0,5% (only PV)
Taxes	34,0%
Maintenance	2.5% (only PV)
Contingency	5% from previous concepts
Annual variation	0,5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**.

The results of the cash flow diagram is shown over the 25 years period studied are shown in the following graphs for each measure included:

Solutions		Description
1	**Lighting**	LED installation and new control strategy

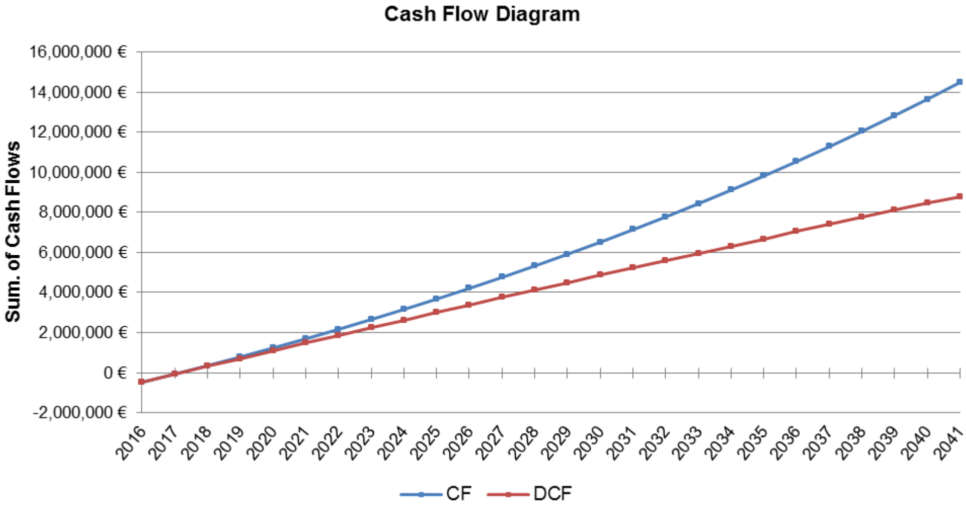


Figure 228. Cash flow diagram S1

The installation of efficient lighting (LED) with better control strategy would have a ROI period of 1.2 years.

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Insulation**	External walls, roof and ground floor with better U-value in order to improve thermal losses

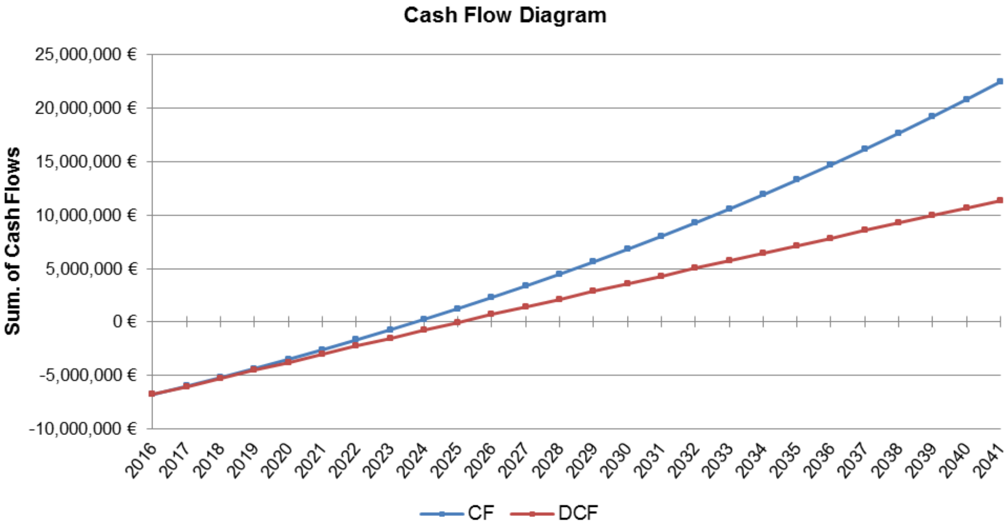


Figure 229. Cash flow diagram S1-2

The installation of efficient lighting (LED) with better control strategy and addition of fiberglass insulation in walls, ground and roof would have a ROI period of 9.06 years (out of 7-years scope).

Solutions		Description
1	**Lighting**	LED installation and new control strategy
~~**2**~~	~~**Insulation**~~	~~External walls, roof and ground floor with better U-value in order to improve thermal losses~~
3	**Green integration**	SE external vegetable walls

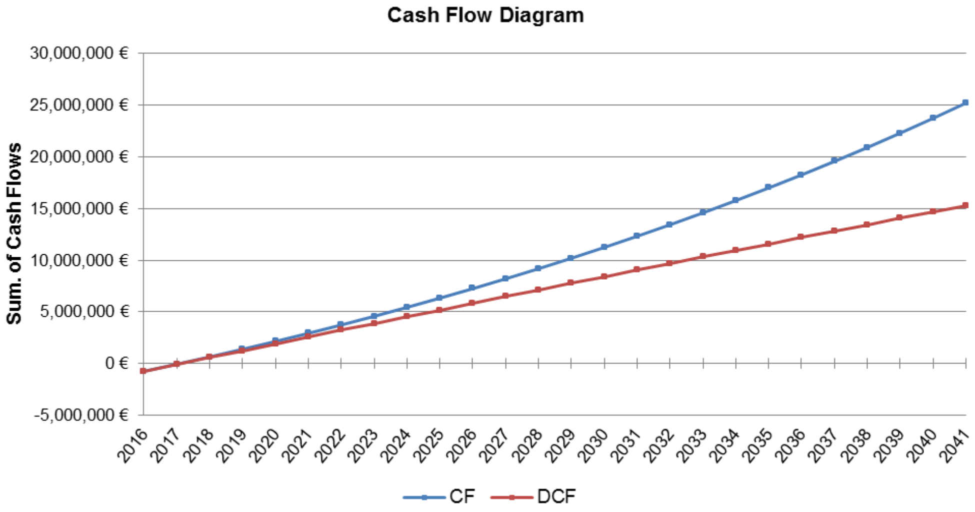


Figure 230. Cash flow diagram S1-3

The installation of efficient lighting (LED) with better control strategy, addition of fiberglass insulation in walls, ground and roof and vegetable SE wall would have a ROI period of 1.11 years.

Solutions		measures
1	**Lighting**	LED installation and new control strategy
~~**2**~~	~~**Insulation**~~	~~External walls, roof and ground floor with better U-value in order to improve thermal losses~~
3	**Green integration**	SE external vegetable walls
4	**Appliances**	Energy efficient appliances, escalators etc.

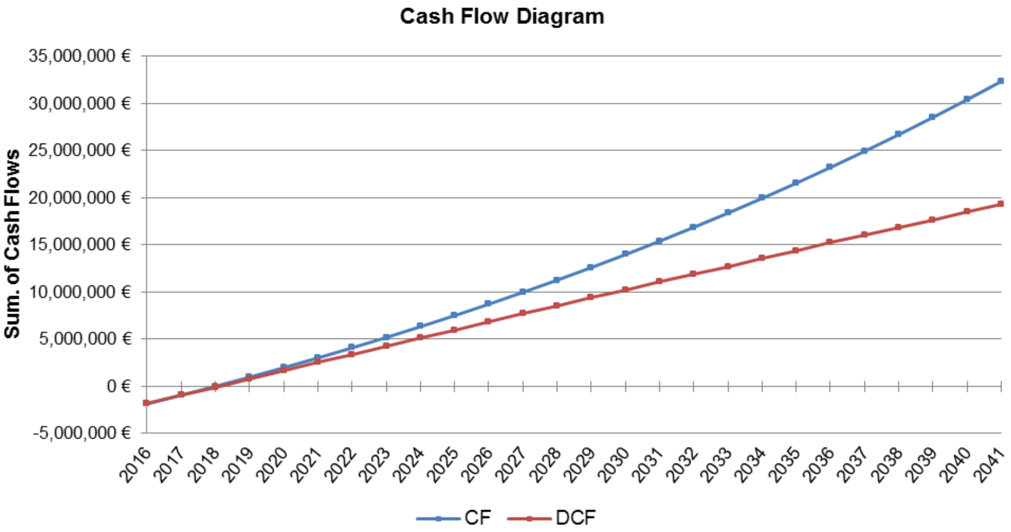


Figure 231. Cash flow diagram S1-2-3-4

The installation of efficient lighting (LED) with better control strategy, addition of fiberglass insulation in walls, ground and roof, vegetable SE wall and more energy efficient appliances would have a ROI period of 1.78 years.

Solutions		Description
1	**Lighting**	LED installation and new control strategy
~~**2**~~	~~**Insulation**~~	~~External walls, roof and ground floor with better U-value in order to improve thermal losses~~
3	**Green integration**	SE external vegetable walls
4	**Appliances**	Energy efficient appliances, escalators etc.
5	**Heat recovery**	Heat recovery equipment integration

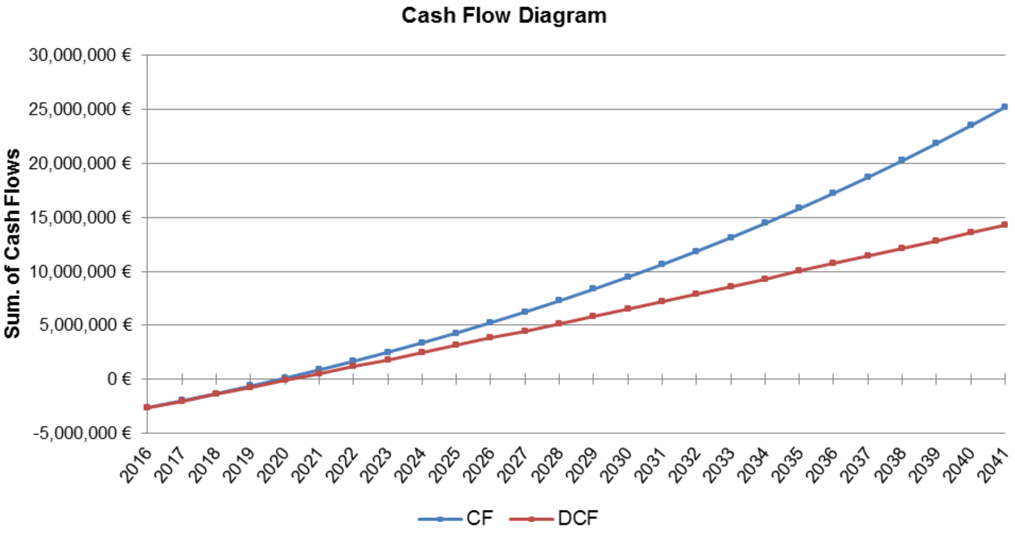


Figure 232. Cash flow diagram S1-2-3-4-5

The installation of efficient lighting (LED) with better control strategy, addition of fiberglass insulation in walls, ground and roof, vegetable SE wall, more energy efficient appliances and a new heat recovery system would have a ROI period of 3.96 years.

Solutions		Description
1	**Lighting**	LED installation and new control strategy
~~**2**~~	~~**Insulation**~~	~~External walls, roof and ground floor with better U-value in order to improve thermal losses~~
3	**Green integration**	SE external vegetable walls
4	**Appliances**	Energy efficient appliances, escalators etc.
5	**Heat recovery**	Heat recovery equipment integration
6.1	**RES – PV**	Photovoltaic panels on the ground

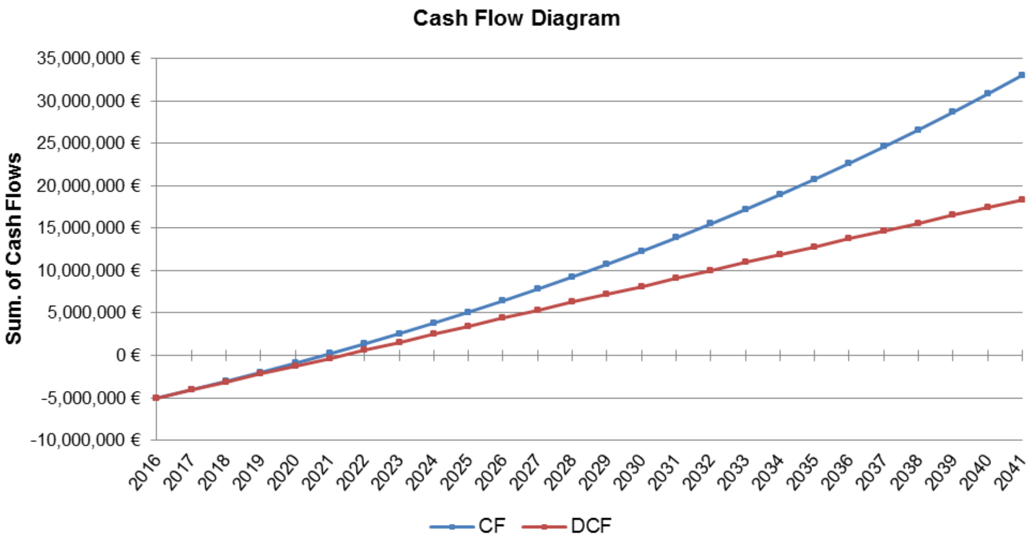


Figure 233. Cash flow diagram S1-2-3-4-5-6.1

The installation of efficient lighting (LED) with better control strategy, addition of fiberglass insulation in walls, ground and roof, vegetable SE wall, more energy efficient appliances, a new heat recovery system and PV panels for electricity production would have a ROI period of 5.77 years.

Solutions		Description
1	**Lighting**	LED installation and new control strategy
~~**2**~~	~~**Insulation**~~	~~External walls, roof and ground floor with better U-value in order to improve thermal losses~~
3	**Green integration**	SE external vegetable walls
4	**Appliances**	Energy efficient appliances, escalators etc.
5	**Heat recovery**	Heat recovery equipment integration
6.1	**RES – PV**	Photovoltaic panels on the ground
6.2	**RES – PV + Batteries**	Photovoltaic panels on the ground + Electrical storage

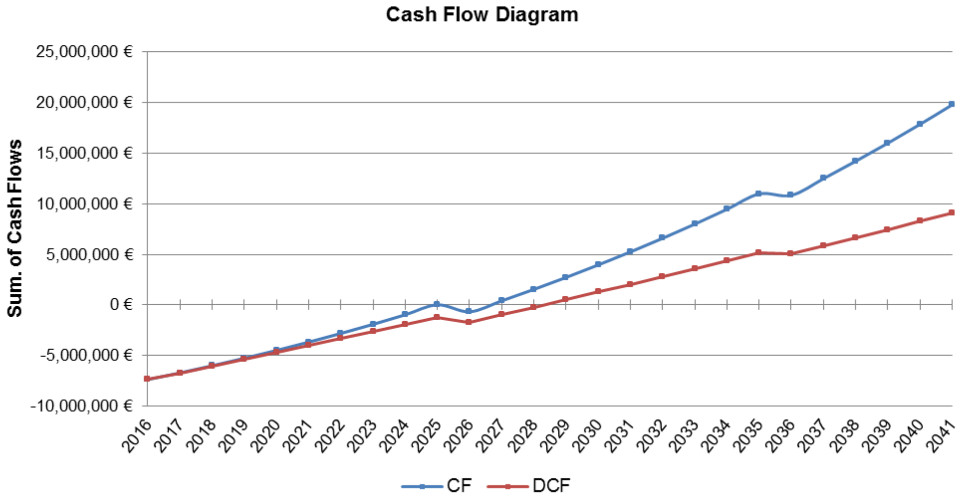


Figure 234. Cash flow diagram S1-2-3-4-5-6.1-6.2

The installation of efficient lighting (LED) with better control strategy, addition of fiberglass insulation in walls, ground and roof, vegetable SE wall, more energy efficient appliances, a new heat recovery system, PV panels for electricity production and electrical batteries for storage would have a ROI period of 12.29 years→ Out of scope (<7 years). The installation of batteries loose the affordability of the solution-set, mainly due to the short lifetime of the batteries (10 years considered).

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Insulation**	External walls, roof and ground floor with better U-value in order to improve thermal losses
3	**Green integration**	SE external vegetable walls
4	**Appliances**	Energy efficient appliances, escalators etc.
5	**Heat recovery**	Heat recovery equipment integration
6.1	**RES – PV**	Photovoltaic panels on the ground
7	**RES – Biomass**	Biomass boiler for heating needs

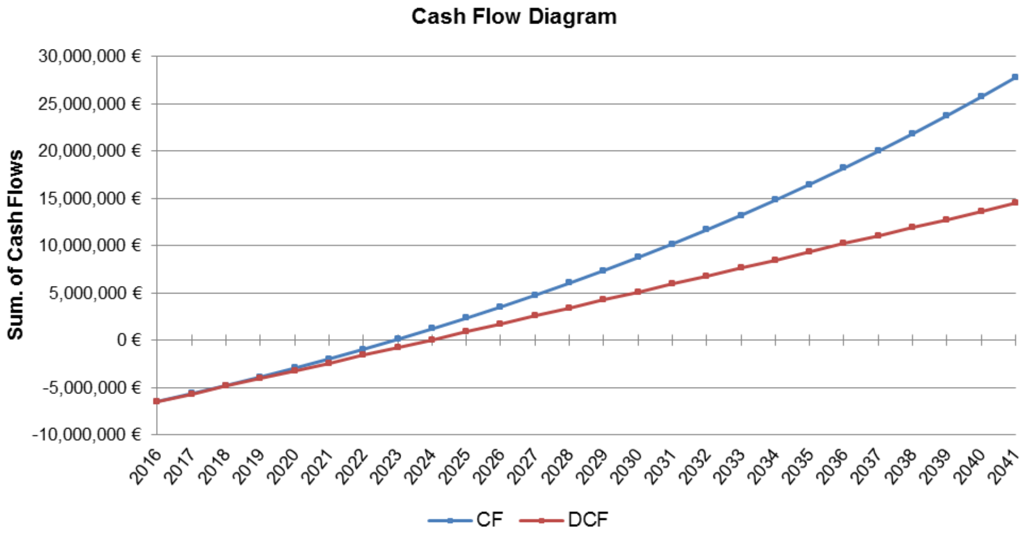


Figure 235. Cash flow diagram S1-2-3-4-5-6.1-7

The installation of efficient lighting (LED) with better control strategy, addition of fiberglass insulation in walls, ground and roof, vegetable SE wall, more energy efficient appliances, a new heat recovery system, PV panels for electricity production and a biomass boiler for heating purposes would have a ROI period of 7.94 years. Again the last solution included (biomass) would not satisfy the requirement of having a solution-set with 7 years payback maximum.

Therefore, solution-set 1 for Waasland will consist on:

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Green integration**	SE external vegetable walls
3	**Appliances**	Energy efficient appliances, escalators etc.
4	**Heat recovery**	Heat recovery equipment integration
5	**RES – PV**	Photovoltaic panels on the ground

A similar study was done in order to evaluate a variation of solution-set1, obtaining solution-set2 with the following composition:

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Green integration**	SE external vegetable walls
3	**Appliances**	Energy efficient appliances, escalators etc.
4	**RES – PV**	Photovoltaic panels on the ground
5	**RES – PV + Batteries**	Photovoltaic panels on the ground + Electrical storage

That is, in this case, the heat recovery system would be replaced by the electrical storage in order to take more advantatge of the PV generation. In this case, the primary energy savings were the same and the economic analysis showed a similar number, 5.89 years.

Conclusions

The solution set here described is balanced on the specific needs of the Waasland building and the climate conditions of Sint-Nikklas.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decided to reduce lighting power density **(solution 1)**. This solution with an investment of 450.000 € offered almost 38% of primary energy savings and 393.550 € of operating cost savings for the building. The implementation of solution 1 would have a payback of 1.2 years.

Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need, but increasing the heating demand. Therefore, a complete retrofit with insulation layer (**solution 2**) is suggested in order to lower back heating need and reduce further cooling need. This solution with an investment of around 6 million €, joined with the previous solution, offered 42% of primary energy savings and 791.480 € of operating cost savings for the building. The implementation of solution 2 (measures 1+2) would have a payback of 9 years due to the high initial investment, the addition of this solution had to be rejected after the economic analysis.

In a further step a green wall concept (foliage) developed in the project was included. It improved the cool demand by 1% (with extension option to 2.5% when E and W walls would be exploited. Also it would improve microclimate by better humidity and pollution moderation. It would enhance the visual effects for clients as well (**solution 3**). This solution with an investment of ca 160 k€ gives cumulative 38% (optionally 39%) of primary energy savings (with Solution 1 and 2). The implementation of solution 3 (measures 1+3) would have a payback of 1.11 years.

The installation of energy efficient appliances is seen as an important further step to reduce energy use in the shopping centre (**solution 4**). This solution with an estimated investment of 675000 €, joined with the previous solutions, offered 47.1% of primary energy savings and 944.310 € of operating cost savings for the building. The implementation of solution 4 (measures 1+3+4) would have a payback of 1.78 years.

The following step done deals with the integration of a new system for heat recovery purpose, since in the building there is not any equipment to recover and save energy from the existing system (**solution 5**) and taking into account that with the first solution (lighting) the heating demand has significantly increased. This solution with an estimated investment of near 2 million €, joined with the previous solutions, offered 50% of primary energy savings and around 1 million € of operating cost savings for the building. The implementation of solution 5 (measures 1+3+4+5) would have a payback of 3.96 years.

Finally, the introduction of RES will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. For this building it would be possible to install PV systems on the ground (on the ground- parking area) with or without electrical storage or other kind of renewable system such as biomass boiler. Firstly, the study of PV system without electrical storage (**solution 6.1**), with an estimated investment of around 1 million € (4600m²), joined with the previous solutions, offered 58.9% of primary energy savings and around 1.100.000 € of operating cost savings for the building. The implementation of solution 6.1 (measures 1+3+4+5+6.1) would have a payback of 5.77 years. If we introduce electrical storage in order to explote more the local generation (**solution 6.2**), the study concluded that, with an estimated investment of 1.5 million € (around 2000 kWh, with 500 kW of capacity), joined with the previous solutions, offered 61.8% of primary energy savings and around 1,150,000 € of operating cost savings for the building. The implementation of solution 6.2 (measures 1+3+4+5+6.1+6.2) would have a payback of 10.6 years. Since the objective was to work with ROIs less than 7 years, this solution had to be rejected. It must be taken into account that the lifetime of the batteries was established as 10 years and, then, every 10 years it was necessary to replace the storage and make a new investment for new batteries, this is why the payback time was longer than others. A new study was done with the hypothesis of considering 25years lifetime (like the PV panels) for the batteries, in that case the ROI was reduced to 8 years (again, out of our scope).

Following with the integration of green energies, and taking solution 6.1 as starting point, the installation of a biomass boiler was evaluated (**solution 7**). This boiler would replace the existing one (1400 kW gas boiler). The study concluded that, with an estimated investment of 3.8 million €, joined with the previous solutions, offered 68.2% of primary energy savings and around 1,130,000 € of operating cost savings for the building. The implementation of solution 7 (measures 1+3+4+5+6.1+7) would have a payback of 16.1 years, again, out of scope.

A summary of the solution-sets studied and the economic assessment performed is shown in Table 52.

Table 52. Solution set 1.

Solutions		Investment	Quantity	Investment individual solution	Total investment	Incomes yearly accumulated	%PE savings accumulated	Payback
1	**Lighting**	10 €/m2	45000 m2	450,000.00 €	450,000.00 €	393,550.00 €	37.8%	<1 year
2	~~**Insulation**~~	~~60 €/m2~~	~~External walls --> 2.5 cm (9093,4 m2)~~ ~~Roof--> 2.5 cm (45315 m2)~~ ~~Ground floor -->3 cm (45315 m2) TOTAL--> 99723,4 m2~~	~~5,983,404.00 €~~	~~6,433,404.00 €~~	~~791,480.00 €~~	~~42.0%~~	~~9.06 years~~
3	**Green integration**	100 €/m2	1576,19 m2	157,619.00 €	607,619.00 €	782,585.00 €	38.0%	1,11 years
4	**Appliances**	15 €/m2	45000 m2	675,000.00 €	1,282,619.00 €	883,005.00 €	47.1%	1.78 years
5	**Heat recovery**	6,2 €/m3h	315000 m3	1,953,000.00 €	3,235,619.00 €	936,835.00 €	50.0%	3.96 years
6.1	**RES – PV**	1500 €/kWp	4600 m2 (3170 modules, 220 Wp each one, polichristaline)	1,046,100.00 €	4,281,719.00 €	1,137,065.00 €	58.9%	5.77 years
6.2	~~**RES – PV + Batteries**~~	~~700 €/kWh~~	~~electrical storage with 500 kW of capacity and 2050 kWh of energy storage~~	~~1,435,000.00 €~~	~~5,716,719.00 €~~	~~1,158,801.30 €~~	~~61.8%~~	~~10.6 years~~
~~7~~	~~**RES – Biomass**~~	~~900 €/kW~~	~~3 boilers of 1400 kW each~~	~~3,780,000.00 €~~	~~8,061,719.00 €~~	~~1,137,053.10 €~~	~~68.2%~~	~~16.10 years~~

In order to explore other solutions, a new study was done obtaining the definition of solution set 2. In this case, the electrical storage was included being the heat recovery system rejected. The results are shown in Table 53.

Table 53. Solution set 2.

Solutions		Investment	Quantity	Investment individual solution	Total investment	Incomes yearly accumulated	%PE savings accumulated	Payback
1	**Lighting**	10 €/m2	45000 m2	450,000.00 €	450,000.00 €	393,550.00 €	37.8%	<1 year
2	~~**Insulation**~~	~~60 €/m2~~	~~External walls --> 2.5 cm (9093,4 m2)~~ ~~Roof--> 2.5 cm (45315 m2)~~ ~~Ground floor -->3 cm (45315 m2) TOTAL--> 99723,4 m2~~	~~5,983,404.00 €~~	~~6,433,404.00 €~~	~~791,480.00 €~~	~~42.0%~~	~~9.06 years~~
3	**Green integration**	100 €/m2	1576,19 m2	157,619.00 €	607,619.00 €	782,585.00 €	38.0%	1,11 years
4	**Appliances**	15 €/m2	45000 m2	675,000.00 €	1,282,619.00 €	883,005.00 €	47.1%	1.78 years
5	**Heat recovery**	~~6,2 €/m3h~~	~~315000 m3~~	~~1,953,000.00 €~~	~~3,235,619.00 €~~	~~936,835.00 €~~	~~50.0%~~	~~3.96 years~~
6.1	**RES – PV**	1500 €/kWp	4600 m2 (3170 modules, 220 Wp each one, polichristaline)	1,046,100.00 €	2,328,719.00 €	1,083,180.00 €	56.0%	3.20 years
6.2	~~**RES – PV + Batteries**~~	700 €/kWh	electrical storage with 500 kW of capacity and 2050 kWh of energy storage	2,481,100.00 €	4,809,819.00 €	1,134,235.00 €	58.9%	5.89 years
~~7~~	~~**RES – Biomass**~~	~~900 €/kW~~	~~1440 kW~~	~~1,296,000.00 €~~	~~6,105,819.00 €~~	~~1,110,083.10 €~~	~~70.2%~~	~~18.41 years~~

Table 54 summarizes results for solution set 1 and 2.

Table 54. Summary

Solution-set	Individual solutions	Investment	Operation costs savings 1st year	Payback	%PE savings	%TCO$_{eq}$ savings
Solution-set1	- Lighting - Green integration - Appliances - Heat Recovery - PV system	4,281,719.00 €	865,070.01 €	5.77 years	58.9%	59.2%
Solution-set2	- Lighting - Green integration - Appliances - PV system - Electrical storage	4,809,819.00 €	789,448.44 €	5.89 years	58.9%	55.7%

Grand bazar (Antwerp - Belgium)

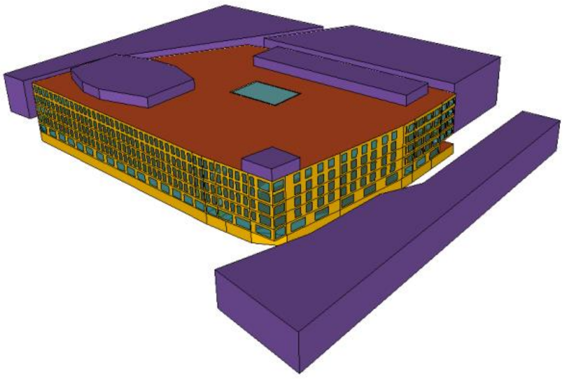
Building model: input data summary

General data	
Gross floor area (inside red figure), [m²]	20403
Common areas and galleries [m²]	3463
Number of opening hours per day [h/d]	10
Number of opening days per week [d/w]	6

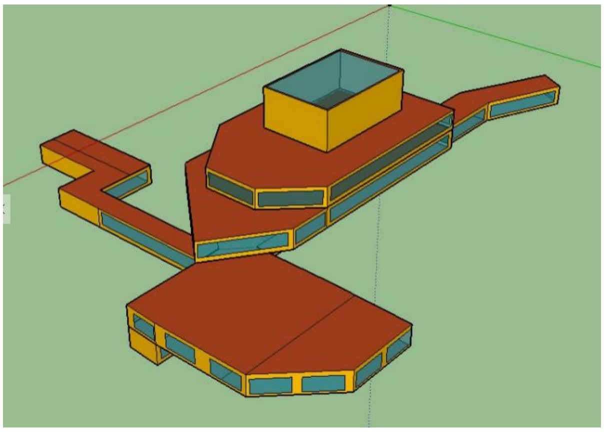
Thermal zone model

Number of thermal zones	21
Underground floor high [m]	3.5
Ground floor high [m]	3.5
First floor high [m]	3.5
Second floor high [m]	3.5

Zone typology	Zone group area [m²]
Shops and Medium Sore	13145
Restaurant	219
Common area	3463
Food shop	362
Warehouse	3214



Several zones, that represent the cafeterias, restaurants, hotels, and the top floors of the building that does not belong to the Grand Bazar, have been defined in the simulations in order to establish the boundary conditions, however they will not be considered for the total energy consumption.



Building envelope		
Opaque envelope components	U-value [W/m²K]	Solar absorptance [-]
Exterior walls	1.23	0.6
Internal walls	5.27	0.6
Exterior roof	1.2	0.6
Ground floor	1.39	0.6
Glazed envelope components	Ug [W/m²K]	g-value [-]
Exterior windows	2.7	
Internal windows	5.68	

	Common areas (CMA)		Shops (SHP)		Medium Store (MDS)		Food Store (FDS)		Restaurant (RST)		Warehouse (WRH)	
	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule	Value	Schedule
People density [pers/m²]	0.2	08:00 – 20:00	0.2	08:00 – 20:00	0.25	08:00 – 20:00	0.25	08:00 – 20:00	0.25	08:00 – 20:00	0.05	08:00 – 20:00
Lighting density [W/m²]	23	07:00 – 22:00	36	07:00 – 22:00	27	07:00 – 22:00	30	07:00 – 22:00	28	07:00 – 22:00	15	07:00 – 22:00
Electric equipment [W/m²]	10	00:00 – 24:00	10	00:00 – 24:00	10	00:00 – 24:00	20	-	10	00:00 – 24:00	10	00:00 – 24:00
Heating setpoint temperature [°C]	20	07:00 – 21:00	20	07:00 – 21:00	18	07:00 – 21:00	20	07:00 – 21:00	20	07:00 – 21:00	20	07:00 – 21:00
Heating setback temperature [°C]	15	21:00 – 07:00	15	21:00 – 07:00	15	21:00 – 07:00	15	21:00 – 07:00	15	21:00 – 07:00	15	21:00 – 07:00
Cooling setpoint temperature [°C]	23	09:00 – 20:00	23	09:00 – 20:00	23	09:00 – 20:00	23	09:00 – 20:00	23	09:00 – 20:00	-	09:00 – 20:00
Cooling setback temperature [°C]	-	-		-		-		-		-		-
Ventilation rates [ach]	2	09:00 – 19:00	2	09:00 – 19:00	2	09:00 – 19:00	2	09:00 – 19:00	2	09:00 – 19:00	2	09:00 – 19:00
	0.82	19:00 – 09:00	0.82	19:00 – 09:00	0.82	19:00 – 09:00	0.82	19:00 – 09:00	0.82	19:00 – 09:00	0.82	19:00 – 09:00
Infiltration rates [ach]	0.4	00:00 – 24:00	0.4	00:00 – 24:00	0.4	00:00 – 24:00	0.4	00:00 – 24:00	0.4	00:00 – 24:00	0.4	00:00 – 24:00

HVAC systems control and efficiency

In the building, we have assumed non-condensing boilers for heating and heat pump for cooling purposes. There is not a heat recovery system.
We considered the following efficiencies to estimate the electricity consumption:

- Gas boiler eff: 0.8
- Air-to-water heat pump EER: 2.5

The heating demand of the mall has been calculated by imposing a set point temperature of 20°C from 7 am to 9 pm and a setback temperature of 15°C during night. The cooling demand has been calculated by imposing a set point temperature of 23°C from 7 am to 9 pm. The cooling system is turned off during the night. No additional air humidification is considered during the winter time.
The heating and cooling system are shut off on Sunday and closing days.

Simulation settings

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling setpoint all the time. The time step is set to 15 min and a preconditioning period of a month is considered.
One weather file is used for the analysis representing the **Typical Meteorological Year (TMY)**, which derives from Meteonorm database (Meteotest, 2015) and is representative of the standard weather conditions.

Actual building energy consumption

Calibration

A calibration has not been done since we did not have enough information for that purpose.

Energy consumption

The following graphs show the heating and cooling demand ratios per each thermal zone and the distribution of final energy (electricity/gas) per use (for the whole building). It can be seen that the highest electricity consumption is due to the lighting.

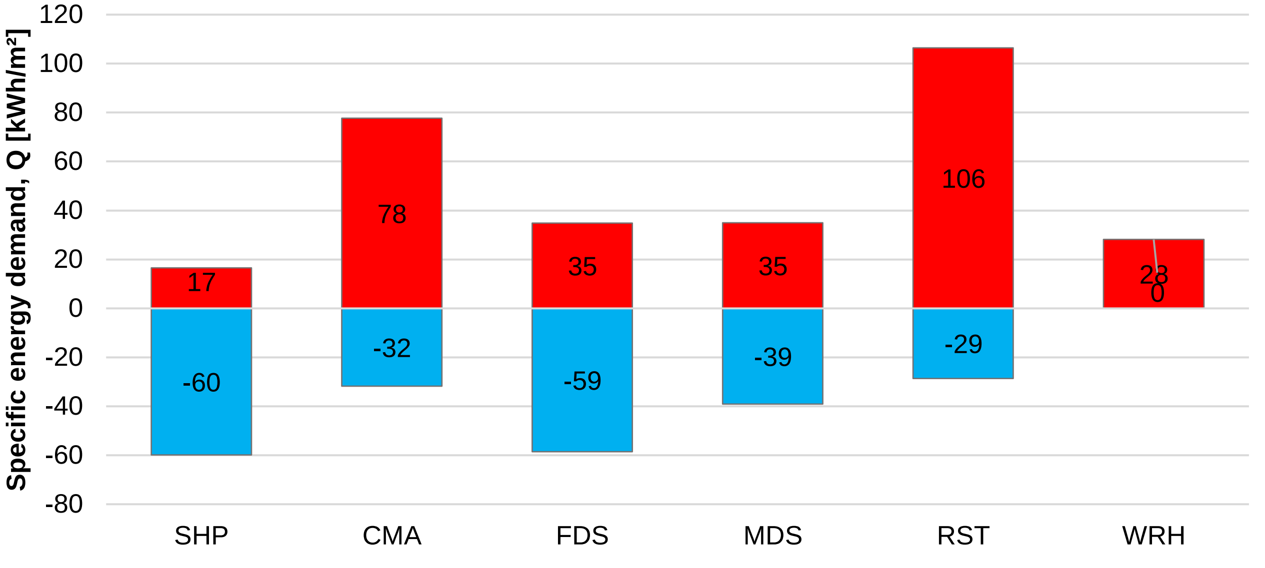


Figure 236. Heating and cooling demand ratios of each type of zone.

Table 55. Heating and Cooling energy demand.

Zone function	Heating (kWh/year m²)	Cooling (kWh/year m²)
Common Areas (CMA)	78	32
Shops (SHP)	17	60
Warehouses (WRH)	28	0
Restaurants (RST)	106	29
Medium Stores (MDS)	35	39
Food Stores (FDS)	35	59
TOTAL	37	37

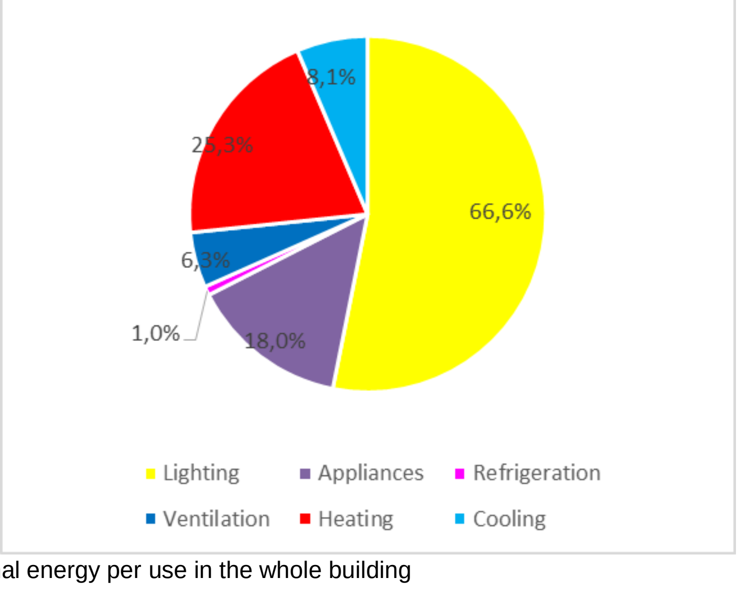


Figure 237. Distribution of final energy per use in the whole building

Solution sets description

The solution set here described is balanced on the specific needs of the Grand Bazar building and the climate conditions of Antwerp. Therefore, its replication in other climates or other buildings need to be further investigated.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decide to reduce lighting power density **(solution 1)**. Internal gains due to lighting reduce accordingly and impact significantly the building energy balance reducing its cooling need, but increasing the heating demand. Therefore, since there is no existing heat recovery system in the buildings, it is proposed to install a new heat exchanger for heat recovery system in the ventilation system of the building (**solution 4**).

The installation of energy efficient appliances is seen as an important further step to reduce energy use in the shopping centre (**solution 2**).

The following step done deals with a new suitable comfort temperature for cooling season, since we think that 23 ºC is quite low for Summer and we would suggest to use the value of 25ºC (**solution 3**)

Finally, the installation of RES **(solution 5)** will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. For this building it would be possible to install PV systems on the roof or other kind of system such as biomass boiler (since the existing boiler seems to be an old one, other solution for improving the primary energy reduction and CO2 emissions, could be to replace the old one by a new condensing boiler with higher efficiency).

Each solution is described in more details below.

Table 56. Summary of solutions

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Appliances**	Energy efficient appliances, escalators etc.
3	**Comfort Temperature**	Use 25ºC instead of 23ºC for cooling season
4	**Heat recovery system**	Installation of heat recovery system for heating needs reduction
5.1	**RES - PV**	Photovoltaic panels on the roof
5.2	**RES – Biomass**	Biomass boiler (or new condensing boiler) for heating needs

Solution 1: Efficient lighting system and controls

Objective	To reduce internal gains and lighting consumption by installing more efficient lighting systems and automatically control lighting switch on/off
Description	Lighting power density is reduced down to 10 W/m^2 in the common areas and galleries and 18 W/m^2 in the vending area (shops, midsize stores, food store) because of the installation of LED lamps. Advanced controls allow to reduce lighting intensity by half during preparation hours, before and after the opening time, and also during night milieu, after sunrise during opening time.
Area of application	Common areas, shops, midsize stores, food store
Expected energy savings	50% reduction of electricity consumption due to lighting; 50% cooling need reduction
Expected impact on comfort	Visual comfort and perception is more stable since the lighting levels in the shops are harmonized with the ones in the common areas. Furthermore, customers perceive a more natural environment and it is expected they stay longer in the shopping mall.
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and building thermal behaviour changes reducing its cooling need. Passive solutions can now have an impact on building energy consumption.
Expected investment costs	LED lighting: 4 €/m^2 (min.price, standard product). LED lighting: 14 €/m^2 (max. price, dimable, A++ product).

Solution 2: Appliances

Objective	To reduce energy consumption for appliances by exploiting existing systems.
Description	Appliances in shopping centres consist of • Distribution Transformers • IT Equipment (non-data center) • Water Treatment/Distribution • PCs (Laptops, Desktops, Monitors) • Cash machines • Kitchen Equipment (in restaurants) • Refrigerators/Freezers (in supermarkets) • Video Displays/Boards • Security Systems • Vending machine • Escalators • Elevators • Security lighting The appliances will be exchanged in maintenance cycles with high efficiency products. It is assumed a reduction of 50% of the energy consumption ratios used as baseline.
Area of application	Common areas, shops, midsize stores
Expected energy savings	38% electricity consumption in the areas; 15% cooling consumption reduction
Expected impact on comfort	The reduced internal heat gains will reduce surface and air temperatures. In summer this will increase comfort, in winter it will reduce comfort.
Interaction with other solutions	The reduced internal heat gains will reduce cooling demand and increase heating demand.
Expected investment costs	15 €/m^{3}h

Solution 3: Cooling set point

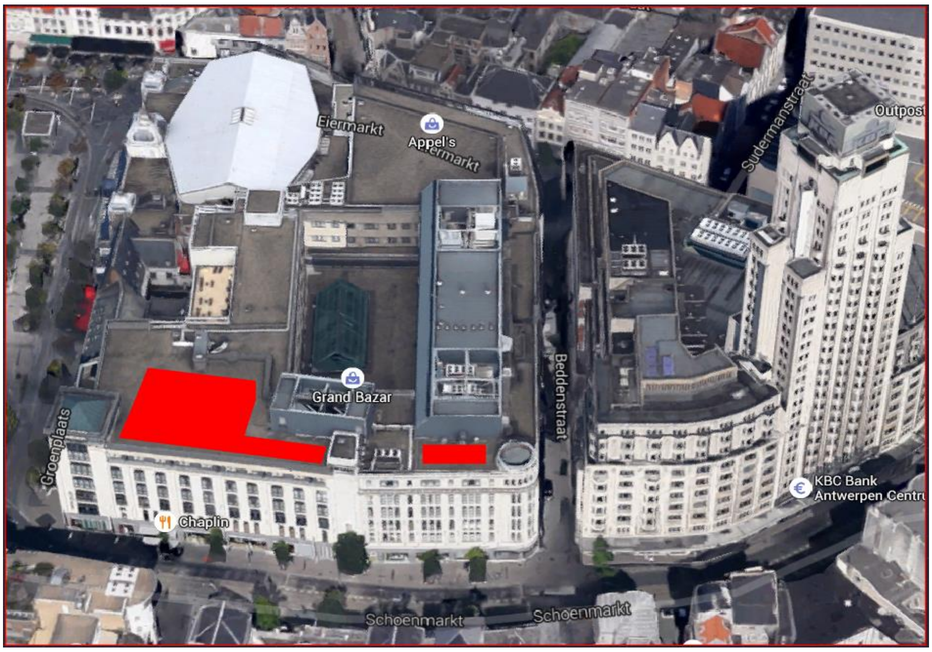
Objective	To reduce energy consumption for cooling by using a different set point
Description	The actual cooling setpoint is 23 °C, it would be possible to increase this value by 25ºC. On the other side, a better control could be used by modulating the cooling setpoint according to the outside temperature in order to prevent big temperature difference between inside and outside that can lead to thermal discomfort to costumers in both summer and mid-season.
Area of application	Common Area, Shops, Medium Store department, Restaurants
Expected energy savings	35% Cooling demand reduction
Expected impact on comfort	A better control of indoor temperature during summer and mid-season preventing thermal shock because of high temperature difference between indoor and outdoor.
Interaction with other solutions	A lower lighting density power helps in reducing cooling demand because the level of the internal gains to be offset is lowered.
Expected investment costs	No investment cost; it is just based on changing controls.

Solution 4: Heat recovery system

Objective	To reduce the heating demand by installing a heat exchanger in the ventilation system of the building for heat recovery.
Description	The heat exchanger will have a performance of 50% and will recover the residual heat that is released to the exterior in the ventilation process.
Area of application	The whole building
Expected energy savings	32% reduction of heating consumption
Expected impact on comfort	Softening of comfort conditions.
Interaction with other solutions	By reducing lighting intensity, internal gains due to lighting are also reduced and therefore the heating demand of the building increases, therefore, the installation of a heat recovery system will reduce such heating demand.
Expected investment costs	6,2 €/m^3h

Solution 5.1: Photovoltaic plant

Objective	Installation of PV plant on the roof to increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO_2 emissions.
Description	The only PV plant can improve the “green-energy” produced on-site and decrease the energy imported from the grid. If the PV is combined with a battery energy storage system, advantageous situation are for suppling a dedicated load (e.g. lighting system) or shave the peak (only to smooth the energy profile and not strictly related to the energy prices during the day). The possible area selected for PV installation could be the following (in red colour):



Area of application	Roof
Expected energy savings	With this solution part of the electrical consumption can be covered combined with a self electricity production with enclosed CO2 emissions reduction, depending on the number of PV panels installed.
Expected impact on comfort	No impact on thermal comfort since it will be potentially installed on the roof
Interaction with other solutions	On-site electricity production can cover part of the lighting electrical consumption
Expected investment costs	1500 €/kWp 292 m^2 (200 modules, 220 Wp each one, polycrystalline)

Solution 5.2: Biomass boiler	
Objective	Installation of biomass boiler in order to decrease the energy imported from other pollutants fuels and the CO_2 emissions.
Description	Since currently the building uses a, antique gas boiler for heating needs, its replacement by a biomass boiler is proposed (or other with better efficiency, such as a condensing boiler).
Area of application	General building
Expected energy savings	Using a biomass boiler with higher efficiency than the existing one, a reduction of consumption for heat production would be achieved with enclosed CO2 emissions reduction.
Expected impact on comfort	No impact on thermal comfort
Interaction with other solutions	Improving the efficiency of the boiler helps in reducing the heating consumption, and using biomass as fuel reduces considerably the Primary Energy consumption
Expected investment costs	900 €/kW Boiler 1000kW

Results

Following, the results obtained after performing the simulation activity and energy/cost balance analysis for the different measures proposed.

Energy and operative costs savings

The graph in Figure 238 shows the actual yearly final energy consumption of the baseline model for the overall shopping mall and the potential energy savings of the energy efficiency measures described previously.

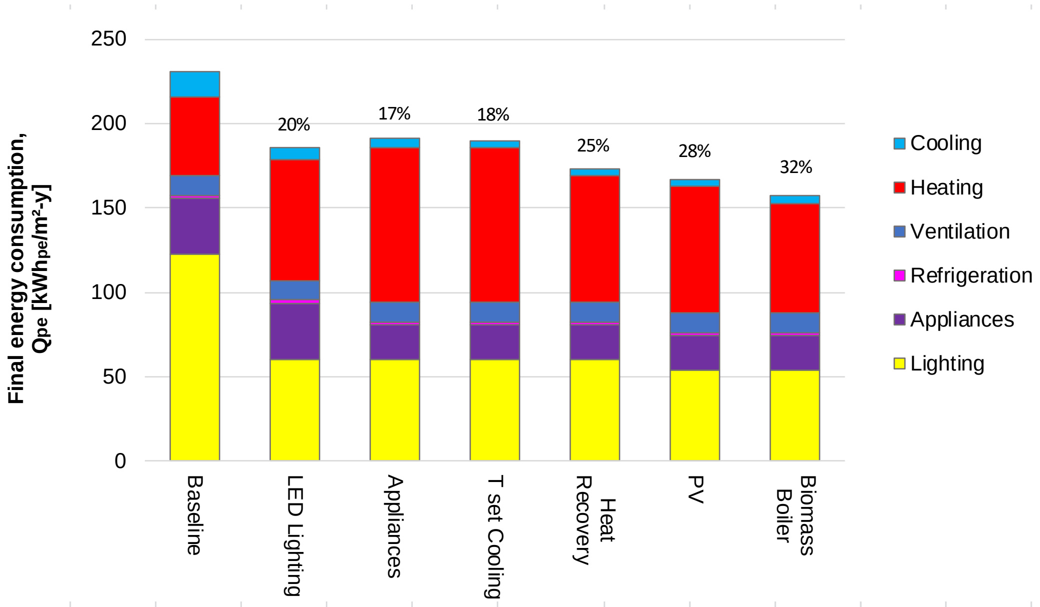


Figure 238 Yearly final energy consumption in Grand Bazar shopping centre

The graph in Figure 239 shows the actual yearly final energy consumption of the baseline model for the common areas and the potential energy savings of the energy efficiency measures described in par.0

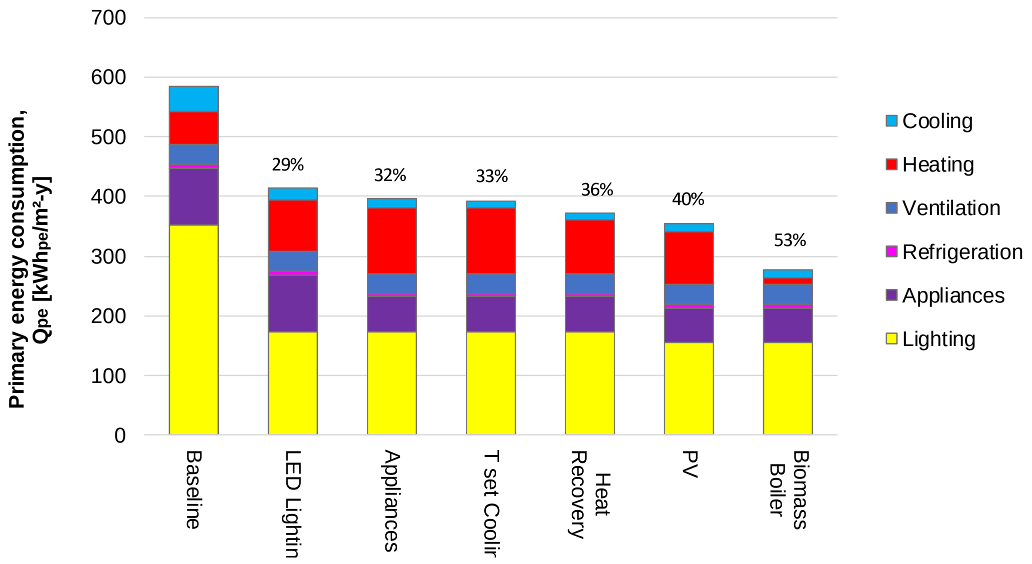


Figure 239. Yearly primary energy consumption in Grand bazar shopping centre

Economic analysis

The economic analysis is based on the assumptions listed in Table 57.

Table 57. Economic analysis assumptions

Assumptions	Value
Year of reference (year 0)	2016
Analysis period	25 years
Discount factor	3,54%
Energy costs	
Cost of gas	0.055 €/kWh
Cost of electricity (buy)	0.17 €/kWh
Cost of electricity (sell)	0.10 €/kWh
Electricity buy price annual variation	3,54%/year
Electricity sell price annual variation	3,54%/year
Installation ageing	0,5%/year
Operation costs	
Insurance	2%
Taxes	1%
Maintenance	1.5% (2.5% only PV)
Contingency	5% from previous concepts
Annual variation	0,5% each

For the viability study of each scenario defined, the **Discounted Cash Flow (DCF)** has been used. Discounted Cash Flow is a cash flow summary adjusted so as to reflect the **time value of money**.
The results of the cash inflows and outflows is shown over the 25 years period studied are shown in the following graphs for each measure included:

Solutions		Description
1	**Lighting**	LED installation and new control strategy

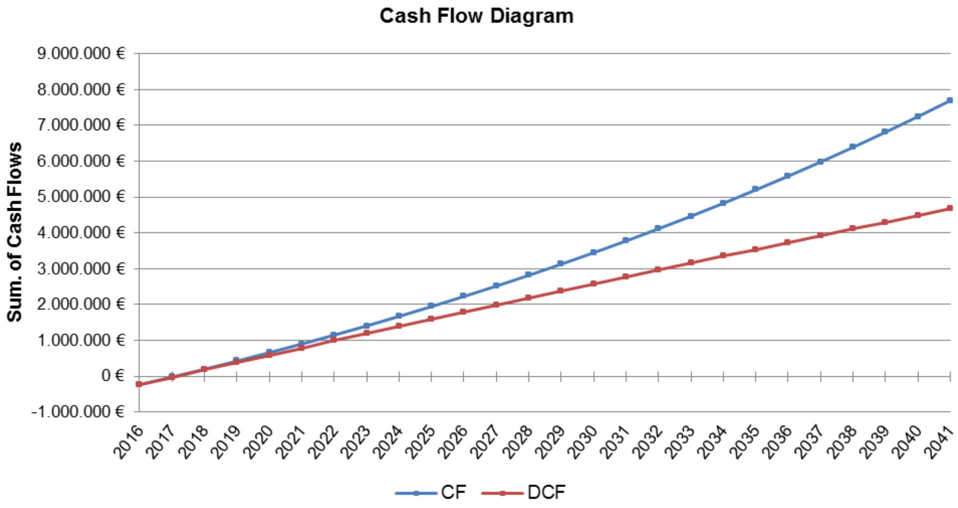


Figure 240. Cash flow diagram S1

The installation of efficient lighting (LED) with better control strategy would have a ROI period of 1.15 years.

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Appliances**	Energy efficient appliances, escalators etc.

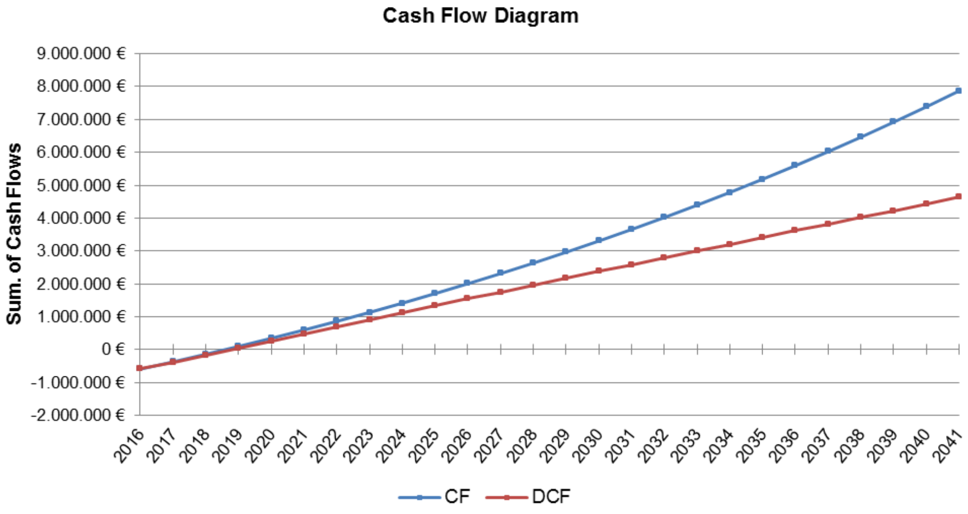


Figure 241. Cash flow diagram S1-2

The installation of efficient lighting (LED) with better control strategy and more energy efficient appliances would have a ROI period of 2.74 years.

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Appliances**	Energy efficient appliances, escalators etc.
3	**Cooling set point**	Reduce Cooling set point temperature 2 Degrees

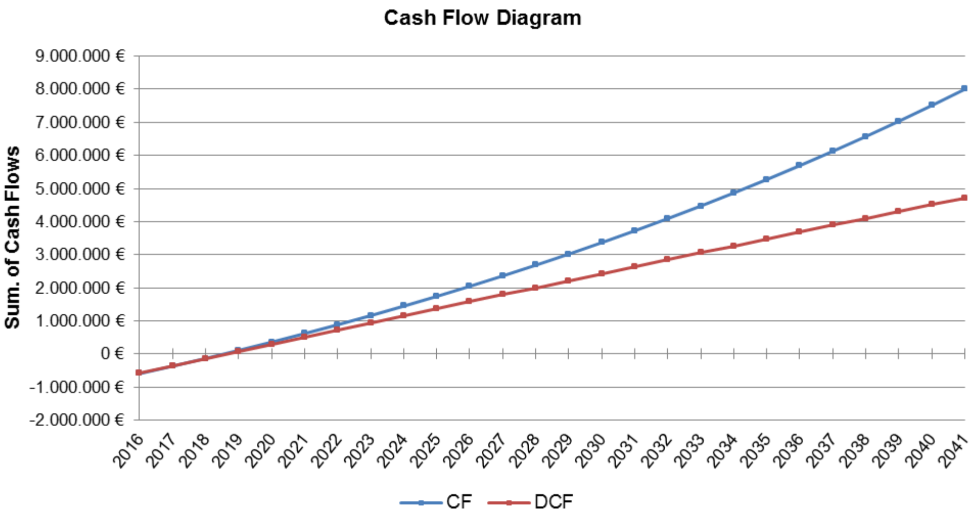


Figure 242. Cash flow diagram S1-3

The installation of efficient lighting (LED) with better control strategy and more energy efficient appliances and the reduction of two degrees the setpoint temperature for cooling would have a ROI period of 2.70 years.

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Appliances**	Energy efficient appliances, escalators etc.
3	**Cooling set point**	Reduce cooling set point temperature 2 Degrees
4	**Heat recovery**	Heat recovery equipment integration

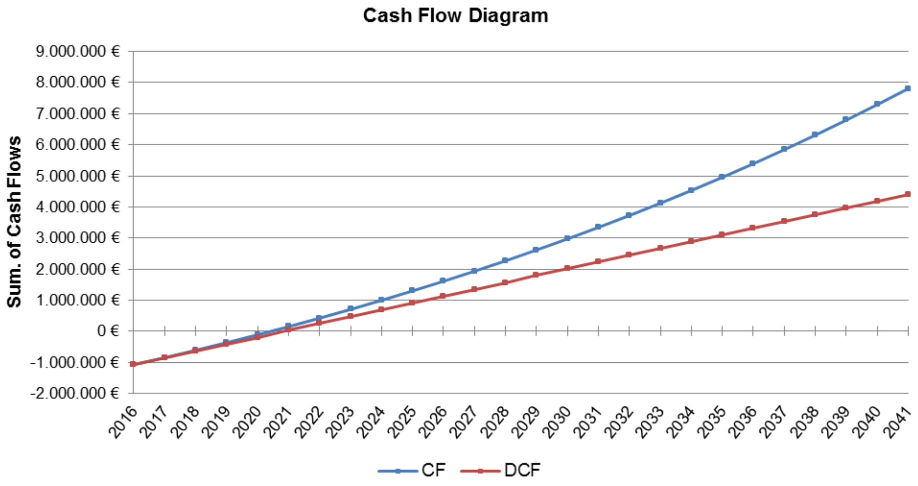


Figure 243. Cash flow diagram S1-2-3-4

The installation of efficient lighting (LED) with better control strategy, more energy efficient appliances and a new heat recovery system and the reduction of two degrees the setpoint temperature for cooling would have a ROI period of 4.86 years

Solutions	Description

1	**Lighting**	LED installation and new control strategy
2	**Appliances**	Energy efficient appliances, escalators etc.
3	**Cooling set point**	Reduce cooling set point temperature2 Degrees
4	**Heat recovery**	Heat recovery equipment integration
5.1	**RES – PV**	Photovoltaic panels on the roof

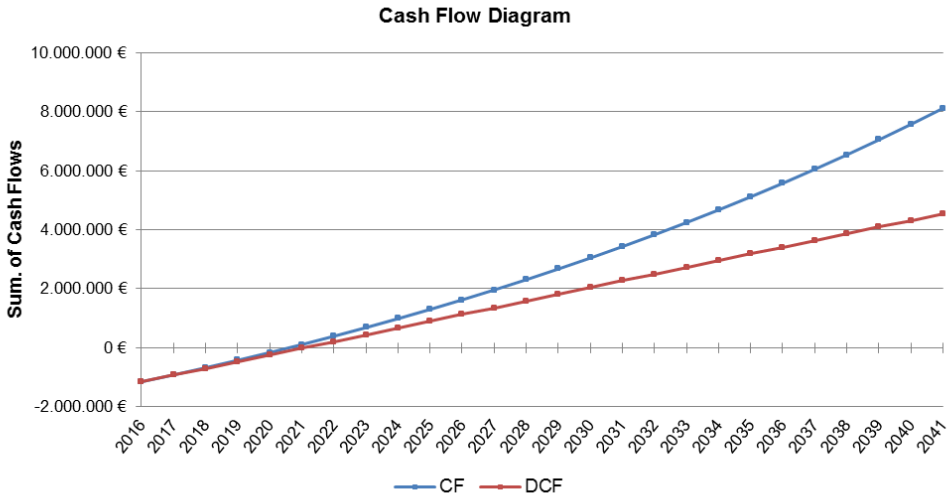


Figure 244. Cash flow diagram S1-2-3-4-5.1

The installation of efficient lighting (LED) with better control strategy, more energy efficient appliances, a new heat recovery system and PV panels for electricity production and the reduction of two degrees the setpoint temperature for cooling would have a ROI period of 5.07 years.

Solutions		Description
1	**Lighting**	LED installation and new control strategy
2	**Appliances**	Energy efficient appliances, escalators etc.
3	**Cooling set point**	Reduce cooling set point temperature 2 Degrees
4	**Heat recovery**	Heat recovery equipment integration
5.1	**RES – PV**	Photovoltaic panels on the roof
5.2	**Biomass boiler**	More efficient Biomass Boiler

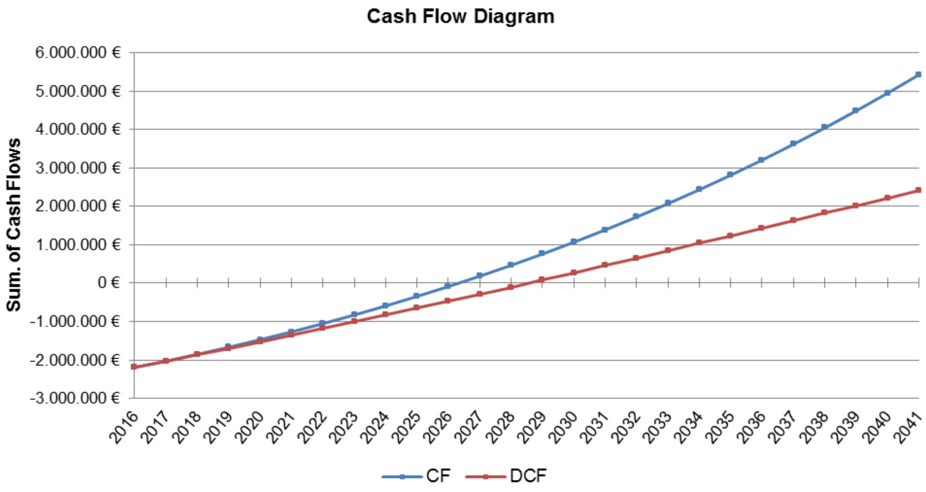


Figure 245. Cash flow diagram S1-2-3-4-5.1-5.2

The installation of efficient lighting (LED) with better control strategy, more energy efficient appliances, a new heat recovery system, PV panels for electricity production and a biomass boiler for heating purposes and the reduction of two degrees the setpoint temperature for cooling would have a ROI period of 12.55 years. The last solution including (biomass) would not satisfy the requirement of having a solution-set with 7 years payback maximum.

Therefore, solution-set 1 for Grand Bazar will consist on:

Solutions		Description
1	**Lighting**	LED installation and new control strategy
~~2~~	**Appliances**	Energy efficient appliances, escalators etc.
3	**Cooling set point**	Reduce cooling set point temperature2 Degrees
4	**Heat recovery**	Heat recovery equipment integration
5.1	**RES – PV**	Photovoltaic panels on the roof

Conclusions

The solution set here described is balanced on the specific needs of the Grand Bazar building and the climate conditions of Antwerp.

Considering the fact that lighting is responsible for most of the electricity consumption of the shopping centre, we first decided to reduce lighting power density **(solution 1)**. This solution with an investment of 204.000 € offered almost 29% of primary energy savings and 205.259 € of operating cost savings for the building. The implementation of solution 1 would have a payback of 1.15 years.

In the same line, the installation of energy efficient appliances is seen as an important further step to reduce energy use in the shopping centre (**solution 2**). This solution with an estimated investment of 306.045 €, joined with the previous solutions, offered 32% of primary energy savings and 214.346 € of operating cost savings for the building. The implementation of solution 2 (measures 1+2) would have a payback of 2.74 years.

It was analysed the possibility to increase the setpoint temperature for cooling (**solution 3**), in order to increase the thermal comfort, preventing high temperature difference between inside and outside that could lead to thermal discomfort to costumers in both summer and mid-season, and also to reduce the cooling demand. This solution with a free investment, joined with the previous solutions, offered 33% of primary energy savings and 217.814 € of operating cost savings for the building. The implementation of solution 3 (measures 1+2+3) would have a payback of 2.70 years.

Reducing internal gains due to lighting and appliances impact significantly the building energy balance reducing its cooling need, but increasing the heating demand. Therefore, it is proposed the integration of a new system for heat recovery, since in the building there is not any equipment to recover and save energy from the existing system (**solution 4**). This solution with an estimated investment of 417.445 €, joined with the previous solutions, offered 36% of primary energy savings and 218.664 € of operating cost savings for the building. The implementation of solution 4 (measures 1+2+3+4) would have a payback of 4.86 years.

Finally, the introduction of RES will increase the self-consumption and self-production, in order to decrease the energy imported from the grid and the CO2 emissions. For this building it would be possible to install PV systems on the roof without electrical storage (**solution 5.1**). This solution with an estimated investment of 66.000 € (300m²), joined with the previous solutions, offered 40% of primary energy savings and around 224.569 € of operating cost savings for the building. The implementation of solution 5.1 (measures 1+3+4+5.1) would have a payback of 5.07 years.

Following with the integration of green energies, and taking solution 5.1 as starting point, the installation of a biomass boiler was evaluated (**solution 5.2**). This boiler with higher efficiency would replace the existing one. The study concluded that, with an estimated investment of 900.00 €, joined with the previous solutions, offered 53% of primary energy savings and around 156.747 € of operating cost savings for the building. The implementation of solution 5.2 (measures 1+2+3+4+5.1) would have a payback of 12.55 years. Since the objective was to work with ROI is less than 7 years, this solution had to be rejected

A summary of the solution-sets studied and the economic assessment performed is shown in Table 58 and **Error! Reference source not found.**.

Table 58. Solution set of Grand Bazar reference building.

Solutions		Description	Primary energy reduction	Payback time
1	**Lighting**	LED installation and new control strategy	40 %	5 years
~~2~~	**Appliances**	Energy efficient appliances, escalators etc.		
3	**Cooling set point**	Reduce cooling set point temperature2 Degrees		
4	**Heat recovery**	Heat recovery equipment integration		
5.1	**RES – PV**	Photovoltaic panels on the roof		

Annex II - Feedback questionnaires from shopping centres owners/managers

Katane': feedback questionnaire

1. Are you directly managing the shopping centre or are you subcontracting the facility management?

IGD is the Katane' landlord and it is responsible for the facility management of the common areas. Shops and food stores are leased by IGD and managed by the respective tenant.

2. How relevant is the tenant in the decision making? What contract with the tenant do you have right now? Is a "green lease" contract in place?

Tenants' consortium is the decision maker and the investment beneficiary. Lease agreement lasts generally 5 year. IGD proposes energy efficiency measures and the tenants' consortium decides whether to finance them. Tenants contract for electricity services and IGD does not have access to their electricity consumption because of privacy reasons. Tenants pay a fixed percentage of the shopping centre's utility bill and maintenance for parking and common areas and for shops air conditioning based on the square footage.

3. How close to the actual building features and management are the model inputs? If not close which is in your opinion the main difference?

Model inputs are closed to design features but tuning is necessary on building management (i.e. setpoints, schedules, lighting features etc...). I do not know in detail them but I can organize a survey with the facility manager.

4. How close to the actual building systems behaviour are the assumptions on HVAC components size, efficiency, control and management? If not close which is in your opinion the main difference?

Model inputs are closed to design features but tuning is necessary on components efficiency and HVAC management (i.e. setpoints, schedules etc...). I do not know in detail them but I can organize a local survey with the facility manager.

5. Do you think that the simulation model results are representative of the actual building energy behaviour? If not representative, which is in your opinion the cause of mismatch?

Yes, they are representative but they need to be fine-tuned with details gathered through a local survey with the facility manager.

6. Are you familiar with the key performance indicators identified and the unit of measure used? If not, which kind of indicator would you like as output of our analysis?

Yes, all our internal communication is based on electricity consumption in kWh. No other performance indicators are being used.

7. Is the results visualization clear? Would you prefer other ways to visualize results?

Results visualization is clear. No suggestion to improve that.

8. What do you think about the technical feasibility of the solutions package proposed (also in relation to the contract you have with the tenants)? How should a contract with the tenant look like in order to implement these solutions in your SC?

Considering that Katane' is quite a new shopping centre (built in 2009) there is no plan for restyling and therefore the main task at the moment is to manage the existing features and component in the most efficient way. Solutions with low investment costs (i.e. HVAC controls, natural ventilation) or with low pay back time (i.e. lamps replacement – 13 months PBT) are the most feasible. Architectural solutions (i.e. roof insulation) can be done only if a restyling is foreseen. We are planning to install a PV plant (circa 500kWp) mounted on a shading system for roof parking lots. We are renting the plant for 15 years by an Esco. Tenants shall pay for their actual electricity consumption. This will be mandatory starting from 2018, according to legislative decree of July 4th 2014, n. 102.

9. How reasonable are the assumptions used in the economic analysis?

Electricity costs need to be reviewed. Other factors seem reasonable but they can vary depending on the investment size.

10. Would you implement these solutions in your shopping mall?

We are looking forward cost optimal solutions which enable us to optimize the energy behaviour of the building with low investment costs. We are not going to implement architectural solutions in the near term. In order for architectural solutions to be cost-effective, they have to be coupled with a restyling operation.

11. Would you suggest other solutions to improve the overall energy efficiency of the shopping centre?

Indoor temperatures and lighting system management are the priorities at the moment.

12. In general, is the study meeting your expectation? If not, what would you expect from this analysis?

Yes, the study is in general very promising and useful to us.

City Syd: feedback questionnaire

1. Are you directly managing the shopping centre or are you subcontracting the facility management?

The management is subcontracted to CitySyd. But the day to day operational management is done by a local company.

2. How relevant is the tenant in the decision making? What contract with the tenant do you have right now? Is a "green lease" contract in place?

The tenants are not active in the day to day decision making, regarding operations in the centre. But within their own space they have total control in regards to cooling / lighting / appliances Green leases are not yet implemented, but we have clauses on energy in the contracts already.

3. How close to the actual building features and management are the model inputs? If not close which is in your opinion the main difference?

The inputs are close to the actual dimensions. The real temperature setpoints in common area / shops / Restaurants / service / warehouse / office are lower than your estimates, due to having to compensate for internal gains.

4. How close to the actual building systems behaviour are the assumptions on HVAC components size, efficiency, control and management? If not close which is in your opinion the main difference?

They are correct. But your heat recovery efficiency rates are quite high considering the age of our HVAC systems.

5. Do you think that the simulation model results are representative of the actual building energy behaviour? If not representative, which is in your opinion the cause of mismatch?

They give a good simulation of our energy consumption. But should be given more “easier” names so to relate to them.

6. Are you familiar with the key performance indicators identified and the unit of measure used? If not, which kind of indicator would you like as output of our analysis?

The KPI are relevant. And seem easy to follow in the reasoning.

7. Is the results visualization clear? Would you prefer other ways to visualize results?

Says In Progress so I’m guessing colours will be applied. Then I guess they would be easier to read and understand. But a tip is to keep the information as simple as possible, considering the audience.

8. What do you think about the technical feasibility of the solutions package proposed (also in relation to the contract you have with the tenants)? How should a contract with the tenant look like in order to implement these solutions in your SC?

As far as heating we are quite set, due to the layout of the existing facilities. In regards to cooling and lighting there are definite advantages in implementing guidelines in the tenant contracts regarding equipment used, and the level of sophistication in the control rules. It will save both the tenants and management operational costs.

9. How reasonable are the assumptions used in the economic analysis?

Variations seems a bit low. Think they are a bit higher.

10. Would you implement these solutions in your shopping mall?
Yes if the owner / developer see`s the cost/ savings benefit of the solutions.

11. Would you suggest other solutions to improve the overall energy efficiency of the shopping centre?
Roof / wall insulation, windows with sun blocking and insulation capabilities, construction materials in the retrofit.

12. In general, is the study meeting your expectation? If not, what would you expect from this analysis?
The study is good. However in order to “sell” this to the investors/ developers/ owners there should be a higher focus on the cost/ savings benefits of the implementation. As the environmental rewards usually come second to cost/ savings rewards. So if the study can show with clear numbers the real benefits economically. It will be easier to take it into consideration.

Waasland: feedback questionnaire

1. Are you directly managing the shopping centre or are you subcontracting the facility management?

We are directly managing the shopping centre.

2. How relevant is the tenant in the decision making? What contract with the tenant do you have right now? Is a "green lease" contract in place?

Unfortunately there are no green leases in place. We have standard lease agreements with no specific clauses towards sustainability. With regards to decision making the tenant isn't so relevant, important decision need to be approved by the landlord.

3. How close to the actual building features and management are the model inputs? If not close which is in your opinion the main difference?

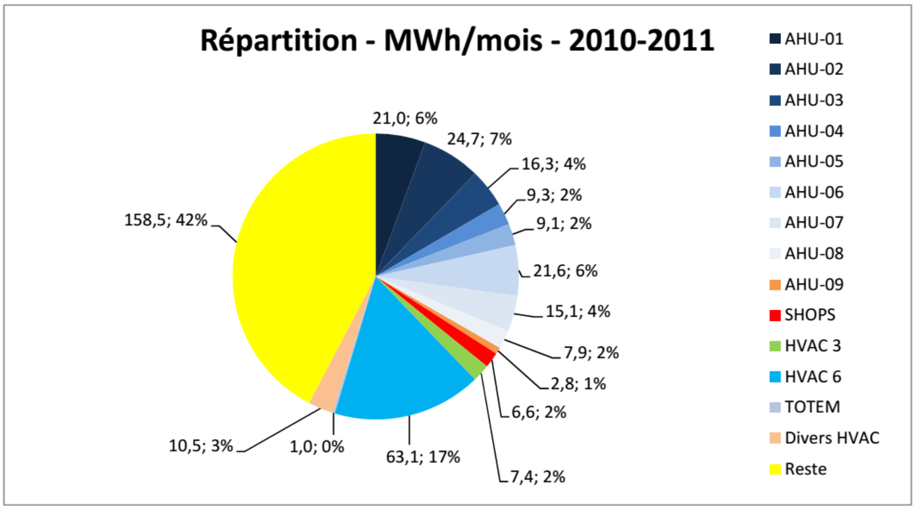
I believe they are a good reflection of the reality.

4. How close to the actual building systems behaviour are the assumptions on HVAC components size, efficiency, control and management? If not close which is in your opinion the main difference?

I've noticed that you take a supplementary heating to 16°C during night times into account. This is not necessary, there is no heating during the night. You mention 13 heat pumps but we only have 10 air handling units (so 10 heat pumps). What do you mean with heat recovery system? To my knowledge there is no such installation in WaSC.

5. Do you think that the simulation model results are representative of the actual building energy behaviour? If not representative, which is in your opinion the cause of mismatch?

We've had an energy study done in 2010-2011 and the graph below shows their results.



All AHU are for common parts, but Shops, HVAC3, Divers HVAC and 80% of HVAC 6 is for the shops only. So if you take that into account, I would believe that following would be more representative: 45% lighting, 40% HVAC, 15% appliances.

6. Are you familiar with the key performance indicators identified and the unit of measure used? If not, which kind of indicator would you like as output of our analysis?

No specific remarks on this item

7. Is the results visualization clear? Would you prefer other ways to visualize results?

No specific remarks on this item

8. What do you think about the technical feasibility of the solutions package proposed (also in relation to the contract you have with the tenants)? How should a contract with the tenant look like in order to implement these solutions in your SC?

If you look at the feasibility I have following remarks:

- *Lighting: We will definitely implement this solution (budget foreseen for 2017-2018) for the common parts. Landlords can't request a certain lighting level of its tenants. In retail the customer experience is only increasing in importance, so every brand/shop wants to emphasize its own concept and lighting is a key element. It is impossible to align lighting levels for mall and shops.*
- *High insulation: I don't think this is feasible from an economical point of view unless you have an entire renovation of the building. If you look at the technical feasibility, I suppose there are enough solutions for wall insulation. However, for the rooftop (parking) it is a lot more difficult since not all insulation types give enough support and/or can hold the pressure.*
- *Appliances: I agree*
- *Cooling set point: perfectly feasible but 26° seems high (often it isn't even this hot outside during summer, it's Belgium not Spain ☺). It would be better if we could implement a flexible temperature. For example:*
    - *outside temperature lower than 16°C: inside 18°C*
    - *between 16°C and 20°C: inside 20°C*
    - *between 20°C and 23°C: inside 23°C (just ventilation with fresh air, no heating/cooling)*
    - *higher than 25°C: inside 23°C*
    - *higher than 28°C: inside 25°C*
    - *higher than 30°C: inside 26°C*

  This is just a draft, but it should be studied which temperatures would have the least impact on comfort, and the highest on energy reduction. (we are working on this).
- *Photovoltaic plant: feasible on other buildings but unfortunately WaSC structures cannot support the supplementary weight. We are looking into the installation of a PV-plan on the southern ground level parking.*
- *Biomass boiler: I don't know enough of this subject to give any interesting feedback.*

9. How reasonable are the assumptions used in the economic analysis?

Analysis is under construction

10. Would you implement these solutions in your shopping mall?

See answers on question 8, so yes, some of them will be implemented.

11. Would you suggest other solutions to improve the overall energy efficiency of the shopping centre?

Apart for the remark I've made under 'cooling temperature ' in question 8, I would recommend everybody to install a high end energy management system. Highest gains can still be found in good management of the installations (alarms when unnecessary or unexpected consumption is measured, thorough analysis of all data…). My (former) colleagues from shopping L'Esplanade (where Mr. Pairoux was facility *manager) were able to reduce their energy consumption with 25% by using this tool. In WaSC we'll be installing such a system this year (investment 170 K€).*

12. In general, is the study meeting your expectation? If not, what would you expect from this analysis?
The result is rudimental, so most of the items have been raised before. It will be interesting to see the economic analysis and the impact on the net value of the building. However this was not the goal why I wanted to participate in this project. I think it was interesting to give you some insights on how shopping centres work and what kind of installations are used. In return I was able to meet other SC managers and got to know on how they work. It was also very interesting to see on how you have been working towards this result, which parameters you take into account (more than previous studies have done) and how those impact the result. So I'm not disappointed, I learned a lot. I think it is not possible to give a more detailed study without visiting the centre and looking into the BMS and installations. (for example for the study in 2010-2011 measurements in the mall and on installations have been done during 6 months).

Donauzentrum: feedback questionnaire

1. Are you directly managing the shopping centre or are you subcontracting the facility management?

Facility management is subcontracted

2. How relevant is the tenant in the decision making? What contract with the tenant do you have right now? Is a "green lease" contract in place?

Every decision related to the mall is under the shopping centre management and energy refurbishment measured of the mall are payed by the shopping centre. For the leased area, refurbishment measures depends on the construction data but in general before rental every 7-10 years depending on tenants last, each shop is refurbished. A green lease contract is in place with all the tenants asking them to be sustainable as possible (e.g. to shut off light at night, etc.) but there is no penalty. Each shop consumption, counted with an electricity meter and HVAC consumption (being the system unique for the entire mall), is then charged based on the size (m²) of the shop. A unique system deliver heating(air system) and cooling(through cold water) to the shops (18°C heating setpoint, 25°C cooling setpoint) but they can use also their own additional cooling system. All tenants have a handover point of heating, cooling and in this way we are able to derive the different consumption between mall common areas and tenants. Regarding the relationship between central management and single shops, we can suggest retrofit solutions to the tenants (e.g. lighting power reduction) but most of the time they decide by their own. As example, in the case of lighting, the lighting level chosen (and consequently the W/m² installed) are sales oriented more than energy savings oriented.

3. How close to the actual building features and management are the model inputs? If not close which is in your opinion the main difference?

In the connection bridge there are also shops.

I don't have skills to evaluate the envelope thermal characteristics, but should be fine based on the fact that the model differentiate the thermal proprieties of the part built in different period.

People density can be cross-checked with people counter data. As general guideline the numbers are the following:

- *19 million visitors/year*
- *60000 people/day generally*
- *100000 people/day over Christmas*

In 2015 we recorded these number of visitors:

Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1,511,841	*1,347,361*	*1,412,494*	*1,344,371*	*1,261,240*	*1,347,631*	*1,461,670*	*1,336,607*	*1,302,137*	*1,499,401*	*1,459,664*	*1,815,144*

All electric equipment are shut off over night. A default value of 0.05 fraction can be set overnight just for taking into account for safety light. Operation time starts 2 hrs before opening (at 7am) during winter while in summer the operation hours goes from 5am until 8pm.

4. How close to the actual building systems behaviour are the assumptions on HVAC components size, efficiency, control and management? if not close which is in your opinion the main difference?

Recirculation is around 60 to 80% depending on air quality measured in the shopping centre. The presence of a CO2 measuring sensors in all the shopping centre allows to have a demand control ventilation. Nevertheless, I do not know which the air changes are.

5. Do you think that the simulation model results are representative of the actual building energy behaviour? If not representative, which is in your opinion the cause of mismatch?

Both electricity consumption and district heating seem representative. HVAC consumption (common areas + air to the shops) is higher than lighting (see monitoring data 2013) for the common areasI would have to take some time to recalculate everything – but measurement-simulation comparison looks good. In general, the model looks good and representative of the real consumption of the all building.

6. Are you familiar with the key performance indicators identified and the unit of measure used? If not, which kind of indicator would you like as output of our analysis?

Generally we use kWh/m² for electricity and m³ for water consumption

7. Is the results visualization clear? Would you prefer other ways to visualize results?

No particular comment on this

8. What do you think about the technical feasibility of the solutions package proposed (also in relation to the contract you have with the tenants)? How should a contract with the tenant look like in order to implement these solutions in your SC?

I am interested in natural ventilation solution and I would like to have more details on how to implement it and the potential energy savings. So that I can propose it to the direction board. It is already forseen to change the lighting concept in the common area. We are oriented into LED technology and we will change also the marble floor in accordance to the lighting concept. A part of the roof will be also renovated and here the possibility to include a portion of automated windows for natural ventilation. A general comment, when we plan a refurbishment action we pay more attention in creating a comfortable environment for costumers than the energy saving connected to the solution adopted.

9. How reasonable are the assumptions used in the economic analysis?

For the economic analysis you can use an electricity cost of 0.10 €/kWh

10. Would you implement these solutions in your shopping mall?

See answer 8

11. Would you suggest other solutions to improve the overall energy efficiency of the shopping centre?

No.

12. In general, is the study meeting your expectation? If not, what would you expect from this analysis?

The study could improve with an energy audit – more detailed info. But as things stand now, we can benefit from it as feasibility study.

Coop Canaletto: feedback questionnaire

1. Are you directly managing the shopping centre or are you subcontracting the facility management?

Coop is directly managing the supermarket area of Modena Canaletto shopping complex while INRES is the engineering company designing and realizing Coop´s supermarket and commercial structure.

2. How relevant is the tenant in the decision making? What contract with the tenant do you have right now? Is a "green lease" contract in place?

not the case (just supermarket)

3. How close to the actual building features and management are the model inputs? If not close which is in your opinion the main difference?

Lighting and electric equipment need some adjustments for both food selling area and food preparation area

4. How close to the actual building systems behaviour are the assumptions on HVAC components size, efficiency, control and management? If not close which is in your opinion the main difference?

In summer, the indoor temperature setpoint varies between 24°C and 26°C depending on the outdoor temperature. Giuseppe can send detail on the control logic. Same in winter.

5. Do you think that the simulation model results are representative of the actual building energy behaviour? If not representative, which is in your opinion the cause of mismatch?

Apart from the above suggested changes, yes it is representative of the actual energy behaviour. Generally refrigeration accounts for 40-50% of the total electricity consumption of a supermarket and based on the results presented it seems that the model works well.

6. Are you familiar with the key performance indicators identified and the unit of measure used? If not, which kind of indicator would you like as output of our analysis?

Yes

7. Is the results visualization clear? Would you prefer other ways to visualize results?

Yes, it is clear.

8. What do you think about the technical feasibility of the solutions package proposed (also in relation to the contract you have with the tenants)? How should a contract with the tenant look like in order to implement these solutions in your SC?

The solution are exactly all the one is going to be physically implemented, so yes they are feasible.

9. How reasonable are the assumptions used in the economic analysis?

Cost of electricity is 0.15 €/kWh

10. Would you implement these solutions in your shopping mall?

All the solutions are the one we are going to implement in Coop Canaletto

11. Would you suggest other solutions to improve the overall energy efficiency of the shopping centre?

No

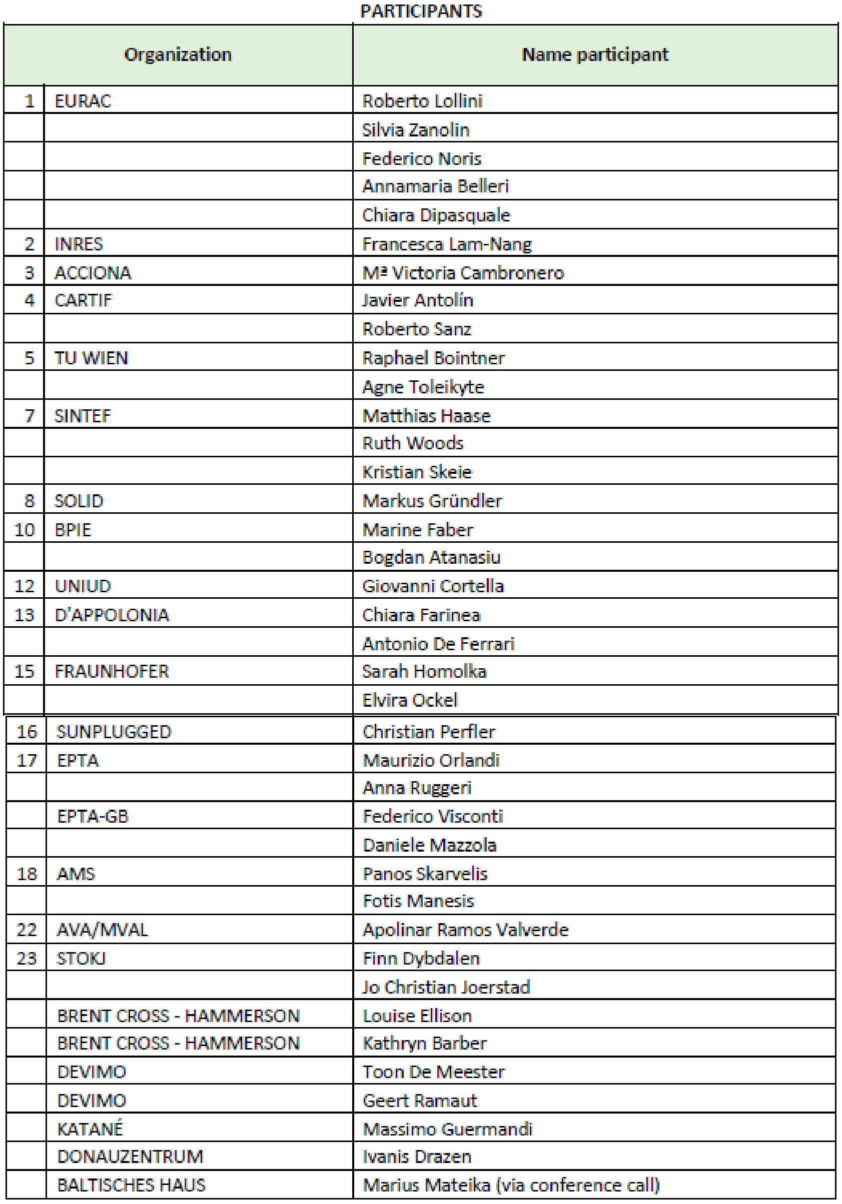
12. In general, is the study meeting your expectation? If not, what would you expect from this analysis?

Yes, expectation are met. We expect some optimization for the mechanical free-cooling operation that can be afterwards replicated in other food store selling point.

Annex III – Stakeholders workshops

Minutes of the Stakeholders' workshop 1

6 October 2014
Wien



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3	ACCIONA	Mª Victoria Cambronero
4	CARTIF	Javier Antolín
		Roberto Sanz
5	TU WIEN	Raphael Bointner
		Agne Toleikyte
7	SINTEF	Matthias Haase
		Ruth Woods
		Kristian Skeie
8	SOLID	Markus Gründler
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13	D'APPOLONIA	Chiara Farinea
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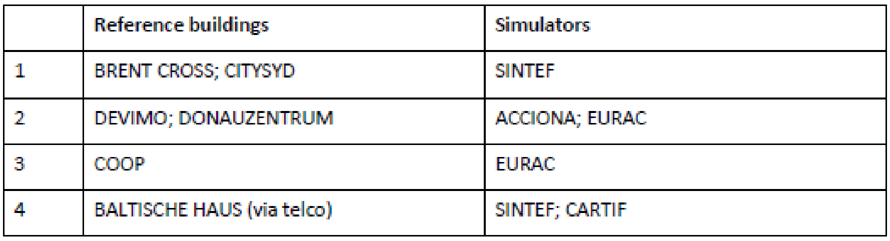
22	AVA/MVAL	Apolinar Ramos Valverde
23	STOKJ	Finn Dybdalen
		Jo Christian Joerstad
	BRENT CROSS - HAMMERSON	Louise Ellison
	BRENT CROSS - HAMMERSON	Kathryn Barber
	DEVIMO	Toon De Meester
	DEVIMO	Geert Ramaut
	KATANÉ	Massimo Guermandi
	DONAUZENTRUM	Ivanis Drazen
	BALTISCHES HAUS	Marius Mateika (via conference call)

The workshop was opened by **R. Lollini, EURAC**, as project coordinator, who presented CommON*Energy* project highlighting objectives (also including specific performance targets), partners involved, general approach, main tasks, technological solutions and methodologies we are investigating. All the participants briefly presented themselves; the project partners highlighted the role of their organization in the reference buildings analysis, while the representatives of the reference buildings clarified which shopping centre they were representing and what is their role within the organization.
After the presentation round, **R. Bointner, TU-WIEN**, showed main results emerged from the mapping of the shopping malls features in Europe (including Norway). **R. Woods, SINTEF**, summarized the typical functional patterns and the socio-cultural context of shopping malls in Europe, analysing who the users

are, how shopping centers function today and how the physical environment supports the retail activity. Starting point was the definition of what a shopping centre is. Finally **M. Haase, SINTEF**, presented the main outputs of the analysis of systemic energy inefficiencies, with a focus on user behaviour – primarily customers and decision making structures associated with landlords and tenants-, inefficiencies associated with the function and use of a shopping centre building, and economic models used to sell energy investment to tenants.

The first part of the workshop was closed by the detailed presentation of the reference buildings, in terms of role (expected activities) and timing. **R. Lollini, EURAC**, explained the selection criteria that have been used to identify the buildings, while **C. Dipasquale, EURAC**, explained the modelling approach used by the researchers team and the expected outputs of the following discussions.

After a short break, the tables of discussion were organized in the four following groups:



	Reference buildings	Simulators
1	BRENT CROSS; CITYSYD	SINTEF
2	DEVIMO; DONAUZENTRUM	ACCIONA; EURAC
3	COOP	EURAC
4	BALTISCHE HAUS (via telco)	SINTEF; CARTIF

Feedback about the workshop

Feedback received by the reference buildings representatives:

(Total feedback forms received: 5. The rating was ranging from 1 very negative to 5 very positive)

- Clarity of: the project content (4,2), role of ref. buildings (4,2), objective of the workshop (3,6)
- Level of: the organization (4,2), venue (3,8), logistics (4,4)
- Quality of: presentations about the project (3,4), modelling and simulations done on the shopping mall to develop possible performance-based systemic retrofitting scenarios and optimize control strategies (3), opportunity of networking with other shopping centres owners/managers (3,8)

Other comments:

Location:

- “I really would have done it in a shopping centre instead of in an outdated room of a university. All shopping centres have large meeting rooms, and I think it would have been a surplus to the study”

Presentations:

- “I realize that time was limited, but that caused that all speakers had to go (too) fast through their presentation. Therefor I wasn’t able to understand everything.”

Face to face tables:

- “For the modelling the researchers made some assumptions that were completely wrong. Therefor the result wasn’t good. I think it would have been better if the preliminary results ware shared in advance of the workshop (for example: through a conference call). The researchers should visit more shopping centers to really understand what kind of building they are”.
- “Good match Brent Cross - City Syd: it was interesting hearing about the regional differences”.
- “It would have been interesting to have other centers in other European countries to share the technical aspects for energy saving”

Feedback collected within the consortium:

o Positive:

- We managed to have a simulation model for each reference building even though the time was very short and the input data has still to be refined. We convinced the ref. buildings owners/managers to provide us more detailed data and even measured data.
- A first contact with the owners, important to know each other and understand the needs of both parts
- The reference building representative people are willing to share with us the available information
- The simulators were pushed to delivers results; we broke the ice and met the managers/owners; I think

(hope) we demonstrated the potential of the work we are doing and therefore we motivated them to provide us with more data
- The workshop was a very good chance to know each other and I am sure this will make easier the data collection and information exchanges in general

o Negative:
- The expectations from reference buildings representative people may have been too high
- The plenary presentations should have been more tailored on the managers/owners and not general
- Reference buildings owners/managers found that simulation results were not realistic and they were somehow skeptic about the reliability of simulation results
- Short time for preparing our proposal and consequently, not robust results
- In some cases there was clearly missing information
- There were some criticisms, because some results were far from the actual performances

o Main output:
- It seems we will have more tight collaboration with the reference buildings owners/managers and we will gather also measured data useful for model calibration and for other studies within the project.
- With a closer collaboration, we can come out with good achievements; both parts (us and owners) seem to be interesting on the proposed work
- We demonstrated the potential of the work and convinced to give us more data

o Attitude of participants:
- Positive and really cooperative.
- Curiosity, willing to understand more, interested
- Quite positive from the majority of the participants

o Suggestions for improvements:
- We need to improve our way to share information (i.e. always charge files on the shared folder in the website and inform partners about new data available). In the next workshop we have to present really effective and justified results and suggest efficient retrofit packages.
- Be prepared and more conscious of the results (lack of experience on the matter, some competences yet to be gained… but will happen soon in the project!)
- Set very well, clearly and honestly the limit and boundaries of what we are doing. Ensure that the outcome presenters (2.1, 2.2, 2.3) do a focused presentation, not a general one; postpone workshop until we are sure and have calibrated models and confirmed the results (via exchange of information via email, calls with owners/managers)
- We are working in a project dealing with shopping centre; this is a very peculiar case within the building typologies: to visit a shopping centre it is always a good chance to better understand the subject of our project

o Concerns
- The owners expect a very detailed analysis of REAL buildings, this could be beyond the originally planned effort in CommONEnergy Description of Work (DoW)

Minutes of the Stakeholders' workshop 2

5 October 2016
Valladolid

Date and location of the workshop	05.10.2016 – Valladolid (Spain)
Author	S. Zanolin, EURAC

Participants list

1	EURAC	Lollini	Roberto
		Belleri	Annamaria
		Zanolin	Silvia
		Pasut	Wilmer
		Dipasquale	Chiara
2	INRES	Lam Nang	Francesca
3	ACCIONA	Rozanska	Magdalena
		Cambronero	Maria Victoria
4	CARTIF	Antolín	Javier
		Sanz	Roberto
5	TU WIEN	Bointner	Raphael
		Toleikyte	Agne
6	SCHNEIDER	Papantoniou	Sotiris
		Mangili	Stefano
7	SINTEF	Haase	Matthias
		Skeie	Kristian Stenerud
8	SOLID	Doll	Werner
9	BARTENBACH	Ampenberger	Andreas
		Pohl	Wilfried
10	BPIE	Faber	Marine
		De Groote	Maarten
12	UNIUD	D'Agaro	Paola
13	D'APPOLONIA	De Ferrari	Antonio
15	FRAUNHOFER	Gantner	Johannes
		Schneider	Sarah
17	EPTA	Mazzola	Daniele
		Visconti	Federico
19	DURLUM	Fröhlich	Benjamin
20	CMS	Grabowiecki	Krzysztof
21	DS Cons	Walger	Christina
		Hiery	Christian
22	AVA/MVAL	Guimerans	Juan Manuel
23	STOKJ	Jorstad	Jo Christian
	Advisory Board	Schröpfer	Veronika

	Advisory Board	Lambert	Deonie
	Advisory Board /Ref. buil. own.	Ellison	Louise
	Reference building owner	Guermandi	Massimo
	Reference building owner	Gentile	Giuseppe
	Reference building owner	Roncaglia	Davide
	Reference building owner	Pairoux	Frédéric

Round Table 1 chaired by A. Belleri and C. Dipasquale, EURAC: focus on Coop Canaletto & Katané reference buildings.

Participants: Massimo Guermandi (IGD), Giuseppe Gentile, Davide Roncaglia (Coop Alleanza 3.0), Daniele Mazzola, Federico Visconti (EPTA), Paola D'Agaro (UNIUD), Francesca Nam-Lang (INRES), Annamaria Belleri, Chiara Dipasquale (EURAC), Sara Homolka (Frauhnofer), Christina Walger and Christian Hiery (DS Consulting).

Questions/discussions:
The discussion has been focused on several aspects of shopping mall deep retrofitting and the solution sets as developed within CommONEnergy: methodology, technical and economic feasibility of solutions, strategies for energy management, possible exploitation of the methodological approach.
Katané (reference building):
PV. The shopping centre owner is leasing the roof to an ESCO which will install a PV plant on the parking canopies and gallery roof. The PV plant will have the same size foreseen by the solution set, will be installed within November and will operate starting from next spring. The lead beneficiary of the RES production is the consortium. So there will be no investment costs for IGD. In the parking area the consortium financed the installation of 700 LED lamps with a payback time of 1 year. This intervention was already considered in the baseline case analysed. The roof leasing contract with the ESCO lasts 15 years. Every 3 years lease can be redefined depending on energy price variation, market, restyling, new anchor store etc. A feasibility study done by an external consulting company suggested to size the PV plant under 600 kW and predicted a self-consumption of 90%. It will produce 30% of the energy of the whole shopping mall. Main reason of the intervention was the greening of the shopping mall at zero investment costs thanks to the roof lease. A co-benefit is also the parking shading. Most of the investment cost of the ESCO is due to parking canopies.
Natural ventilation. IGD is interested in investing in natural ventilation and they are trying to estimate the cost of intervention. Windows already have motors but they are used just for smoke ventilation and they need to be connected to the existing BMS. The solution seems cost-effective. However, Katane' is a quite new shopping mall (constructed in 2009) and it is hard to propose new investments. Generally, restyling interventions occur after 15 years, but they also depend on the market. Another issue is that this kind of interventions do not allow to increase the energy performance certificate class of the building, which would increase the value of the property. Every year they estimate the value of the property and it generally decreases significantly. In the case of natural ventilation, the consortium shall be the investor, since it will also benefit from the energy savings. However, these kind of interventions are not considered as strictly necessary, even though they will reduce operational costs. Another option is to split the

investment over the leases, but IGD cannot increase the rent. Restyling can be planned when a lease finishes or for instance when a new midsize/anchor store is opening.

HVAC management. The cashiers' area of the food store is critical because of air distribution – no integration between HVAC management in the common areas and in the food store. They are managed by different BMS. Thanks to the people counter, IGD estimated that Katane' attracts on average 9.000-10.000 people over the weekdays, up to 20'000 in the weekend. They are installed mainly for commercial purposes, but it would be interesting for them to define control logics based on people inflow. Decentralized plant is necessary because of the large area of the mall. Therefore, it is complex to split the consumption among the tenants depending on their actual consumption. IGD commissioned energy audit to check the BMS management in their shopping malls. They are also introducing detailed monitoring (hourly) on final energy uses.

Experiences in other shopping malls restyling. In the past 5 years IGD activities focused mainly on retrofitting. They opened only one new shopping mall. In the deep retrofitting of Centro Sarca (MI) shopping mall IGD invested ca 7 million €. Among the shopping malls managed by IGD, it is the first one awarded with a BREEAM certification. The restyling involved also the partitioning of lighting area control. The food court and the Cineplex area are opened until 2 am. The portioning of lighting area allows to turn off the lighting in the rest of the shopping mall and keep lighting on only where they are needed. Area portioning in terms of control could be an effective energy efficiency measure - to be considered also in the solution set. Another solution implemented in Centro Sarca is the heat recovery in the air extractors. In the retail park in Chioggia, IGD is going to install a PV plant connected to electric bike charging stations.

Shopping mall management vs tenants. Several issues related to the common areas management and tenants interactions obstacle the implementation of energy efficiency measures: 1) Tenants pay a fixed percentage of the shopping centre's utility bill and maintenance for parking and common areas and for shops air conditioning based on the square footage. 2) Lease states that tenants shall comply with several requirements, such as lighting power density lower than 40 W/m², but the shopping mall management cannot check if they are complying with these requirements because tenants have their own connection to the grid. 3) ESCO seems a profitable solution but their financial statements last more than 5 years while tenants lease are based on annual budget for management and operating costs. Interventions with low investment costs are more easily accepted by the consortium.

Coop Canaletto (demo case)

After the opening of the new Coop Canaletto, they noticed an increase in sales, which after a restyling is also expected. Furthermore, the new food store layout is quite innovative because it reminds the market layout.

Light tubes: Alleanza 3.0 is installing light tubes systematically as deep retrofitting action. They have also been able to reduce installation time by assembling the tubes with the sheath before sending them to the construction site. Apart from energy savings, the light tubes increase visual comfort and allow to comply with law requirements in terms of hygiene and health. This allowed to have food preparation area in the middle of the supermarket and therefore a more innovative layout. Light tubes drive daylighting into the building but causing less overheating compared to skylights.

Refrigeration: due to the small size of the supermarket, refrigeration in Coop Canaletto is responsible for over 40% of the overall energy consumption. Alleanza 3.0 is interested in testing the ejector for which the new refrigeration plant already has a predisposition. Coop Canaletto demonstration activities can be focused on HVAC and refrigeration plant. Because of the small size of the supermarket, recovering waste heat has a higher energy saving potential compared to the ejector and the parallel compression. Especially in small size supermarket, it is important to integrate HVAC and refrigeration design. Low heating need, thanks to closed cabinets, could be almost totally covered by waste heat from refrigeration. Unfortunately, common practice is that refrigeration design occurs after the HVAC design foreclosing potential and energy efficient interactions.

Round Table 2 chaired by M. Haase, SINTEF: focus on CitySid demo & Brent Cross, reference buildings.

Participants: Matthias Haase and Kristian Skeie (SINTEF), Louise Ellison (Brent Cross), Wilmer Pasut (EURAC), Jo Kristian Jørstad (CitySyd), Andreas Ampenberger (BLL), Benjamin Fröhlich (DURLUM), Johannes Gantner (FRAUNHOFER).

Questions/discussions:

The first part of the workshop was a presentation of the three cases: City Syd, Brent Cross, Donauzentrum: Discussion of similarities and differences of the 3 SC; Simulation work discussion (focus on Brent Cross and City Syd, no representative from Donauzentrum); Possible solution sets discussion (focus on Brent Cross and City Syd, no representative from Donauzentrum). As a general comment more robust technology solutions (clear features, reliable performances and viable implementation and maintenance) make easier and faster the decision process on investment (e.g. it is out of discussion to move towards LED in case of lighting replacement, but using of light tube would need costs/benefits analysis and discussion to convince the management in investing).

The second part was focused on heating and airtightness issues: discussion of different solutions for entrance doors, such as new air curtain in Brent Cross, control of natural ventilation in CMA vs. shops; discussion of heating and cooling in CMA and shops, mostly cooling demand in shops, heating in CMA; discussion on tenants role in refurbishment, types of contracts, energy costs vs. turnovers.

The third session was focused on lighting strategy: presentation of lighting cases in City Syd, light tubes in Jens Hoff shop was evaluated as very interesting; discussion of lighting cases 4 and 5, differences, cost-benefits, realization issues, suitable areas for roof openings, high investment costs; discussion on tenants role in lighting cases, focus on realization in shops, high investment costs.

Final decisions and next steps are:

Finalization of solution sets for City Syd as presented

SINTEF will ask Luise to provide more detailed information for Brent Cross

Luise will get SINTEF in contact with manager of Brent Cross

SINTEF will prepare solution sets divided into CMA and shop areas (if sufficient information from tenants can be gathered)

Round Table 3. chaired by M. V. Cambronero, ACCIONA: focus on Valladolid demo + Waasland, GranBazar, Silute, Pamaris reference buildings

Participants: Maria Victoria and Magdalena Rozanska (ACCIONA), Frédéric Pairoux (Devimo), Roberto Lollini (EURAC), Javier Antolín (CARTIF), Maarten de Groote (BPIE), Agne Toleike (TUW), Sarah Schneider (FRAUNHOFER), Krzysztof Grabowiecki (CMS).

Questions/discussions:

Firstly, Waasland work and results were presented to DEVIMO. It was explained why the solutions studied were chosen and which one were rejected from the solution-set justifying the reasons. Since one studied solution was the green integration concept and CMS partner was in the table, he explained more in deep how it works and benefits/constraints of the solution (its particular application in DEVIMO did not offer high savings due to the weather conditions, mainly wind, and the small available façade comparing to the overall area of the shopping centre). 2 solution-sets were proposed with similar numbers in payback time and primary energy savings.

We discussed about the size of retrofitting investment as resulting from the simulations outcomes. DEVIMO usually have a multiannual approach as kind of business model for shopping centre (continuous) renovation, and in this vision, the overall figure seems viable. It would become very important to define a segmented full retrofitting, whose implementation should be planned in the mid-term period, avoiding a very large unique investment.

It is important to define in the right way the performance indicators, to allow a fair comparison. DEVIMO is using energy per GLA (Gross Leasable Area meaning gross conditioned area) per opening hours (unit: kWh/m2/h). Final energy (determining energy bill) is mainly used for energy/facility management, while primary energy more for policy in framework like smart city or climate plan.

On retrofitting supporting tool we identified the economic assessment tool (T5.2) for developing retrofitting drivers in the very early design phase (concept) and IME (T4.1) + detailed framework (as defined within T5.1) for economic analysis to support further design stages.

Main feedbacks received from DEVIMO were:

Lighting retrofitting (using LED technology) → Fully agreement on its benefits and need to be optimized

Lighting control → DEVIMO usually have three levels: (i) off, (ii) service/preparation/cleaning, (iii) business/selling. Reducing lighting means increasing heating demand, maybe introducing a not cost-effective need of increasing insulation to guarantee good comfort conditions. Lighting control strategy must be developed with marketing–driven selling approach (not being clear the basis of such pure marketing drivers)

Green integration → As said before, CMS explained and it seems that for this building would not generate high impact in energy/economic savings (although architectural/visual impact and shopping centre attractiveness to customers could be a plus). In general greenery integrated envelope becomes an heat flux moderator affecting surface temperature by shading, changing convection and radiative factors, modifying thermal capacity; greenery integration should be avoid both on North and South façade.

Appliances → DEVIMO mentioned that this point was quite important because it was studied that by making a good operation control of some appliances like elevators or escalators (for instance moving 2 hours their operation) they can be obtained quite important savings.

Heat recovery → DEVIMO was interested in this kind of equipment because he mentioned that many shopping centres in Belgium did not have heat recovery systems in their buildings, however the investment was quite high, so it would be necessary to evaluate if this system is really necessary taking account their heating demand.

PV system → After the analysis it was conclude that this is a very good solution to take into account and DEVIMO was interested, mainly for the idea of install them on the roof by using canopies (since it is a parking). In fact, in Belgium, they receive revenues for generating clean energy.

Electrical storage → For complementing the PV system it is a good solution, although the investment is quite high and it should be designed very carefully with the PV field capacity in order to optimize the system as a whole. Being a quite new topic they do not have a specific business model on that, but in general the use of batteries depends on energy demand profiles, costs, possible achievement form environmental point of view (reducing CO2 emission by increasing the share of RES); learning curve on cost-effectiveness is missing to enable the planning possible application in the short term.

Internal gain → DEVIMO usually considers the following standard figures for people density: 1p/3m^2 in selling area (common area); 1p/10m^2 in the (food?) store; 1p/1m^2 in the restaurant area; they do not have typical actual value or daily profiles.

Renovation process → it usually has two drivers chaired by facility department (dealing with energy and performance-based) and marketing department (working for improving customers experience and usually approaching renovation on qualitative basis coming from survey/interviews to the customers).

On the other side, DEVIMO explained that although they are very interested in promoting the energy savings, not only under the economic point of view but also considering the environmental issue (they even receive incentives for achieving some KPIs defined), it was very important to try to convince tenants that they have to change their habits (turn off the light if nobody is present, for instance). This is something out of energy managers hand and very important for energy consumption reduction. In fact, they are already doing meetings with tenants (yearly environmental meeting to increase awareness that could be more frequent) in order to explain the importance of “good habits” in energy behaviour, however, it seems that they have not fully succeed for the time being. A possible idea could be to increase facility department budget as a percentage of the energy/economical saving.