Sounds for Energy Efficient Buildings (S4ECoB)

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Abstract

Although modern buildings and spaces of public use include context-aware sensing using video, voice, temperature measurements, gas detection, etc. sounds and noises are often underused in building ICT. Given the importance that humans attribute to both _tilize__g and rare sounds in their living/working open/closed environments, sound based ICT can be particularly useful in providing valuable information for creation of sustainable, energy efficient building indoor and outdoor environments. Sounds contribute to the nature of living/working environments, affecting human behaviour, cultural, spiritual and psychological states and supporting activities. The reliable identification, localization and classification of sounds and noises constitute a clear and significant progress beyond State-of-the-Art, both within micro-sensors for _tilize__g energy efficiency as well as controlling services. S4EcoB will add the parameter of "occupancy" in the monitoring and energy management control systems of buildings and surroundings to _tilize_ the operation of, and eliminate unnecessary consumptions of Heating, Ventilation, Air Conditioning and Lighting, maintaining users' comfort. This will be achieved through development of a novel ICT network of low-cost audio sensors which will integrate with already installed Building Management Systems (BMS) and _tilize building controls. The development of new acoustic information processing technologies will be followed by a validation phase, when the audio sensors will be strategically distributed in the main areas of a regional Airport terminal and two Shopping Centres, and thoroughly configured to provide information about human presence and occupant density. The validation will include ecological, social, economical and financial analysis. This will demonstrate that the energy savings and benefits justify the investment, provide new market solutions for the construction sector and raise awareness of and support regulation on the reduction of climate change. Three locations were identified as pilot projects: Príncipe Pío Shopping Centre in the centre of Madrid; Maremagnum Shopping Centre located in the Port area of Barcelona and Linate Airport, close to Milan.

Keywords: *Sounds, Energy Efficiency, ICT, Buildings*

1. Concept and Objectives

The project Sound for Energy Control of Buildings (S4ECoB) builds a simple and cheap ICT solution for Energy-efficient Buildings (EeB). This Building Energy Management system Optimizer (BEMO) (see

Figure ***1***) is mainly composed of three parts: the Audio and sensor system for listening and sensing, the Acoustic Processing System for detecting and learning acoustic events in order to discriminate levels of occupancy and types of activity and the Management System for monitoring occupancy levels, conditioning and comfort, optimizing the strategies for control of the building automation system and quantifying and visualizing energy consumptions and economic savings.

The proposed work aims at conducting systematic development and integration of tools for monitoring and processing sounds and noises for an accurate determination of the types of occupancy and activities inside and outside smart buildings in order to improve the Building Energy Management (BEM) systems and in consequence to optimize the Energy efficiency in Buildings (EeB). The S4ECoB platform will integrate other existing HVAC systems, such as heating, ventilation, air conditioning, etc. The control and management of automation systems will be based on advanced control strategies. S4ECoB will record and report the control operations, quantify the energy savings, total cost of operation, CO_2 footprint reduction and calculate the return of investment (ROI) and pay-back of the investment.

The main objective of S4ECoB is to deliver the following prototypes and artifacts:

- **Objective 1. Embedded Acoustic Processing Unit (APU).** cheap, energy-efficient but capable, adaptable and scalable embedded audio processing HW/SW platform;
- **Objective 2. Occupancy Sensor.** easy-to-install device which monitors the occupancy level in buildings and surrounding areas and transfers the data in near real-time to the BEMO;
- **Objective 3. Acoustic water flow metering.** scalable air/water flow metering system for HVAC systems transferring sensor data wirelessly to central control and optimization units;
- **Objective 4. A central Acoustic Processing Server (APS)** processing unknown sounds (in non-real time) and managing retraining capabilities (including access to online sound data bases in the Internet).
- **Objective 5. BEM Optimizer (BEMO)** management system. central unit connecting building energy management (BEM) system with occupancy data and establishment of energy consumption baseline through energy audit definition and implementation;

- **Objective 6. Manual for use, installation, integration and set-up.** guide for installation, integration and calibration of the BEMO system and verification of BEMO performance measurement accuracy;

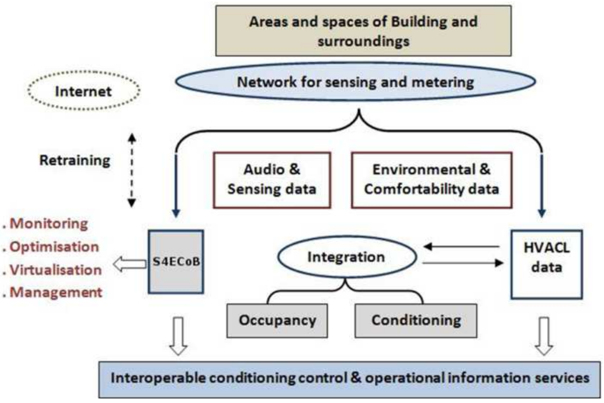


Figure 1. Architecture and data flow of Building Energy Management System Optimizer (BEMO)

2. Acoustic sensing, computing and processing area

The Audio-Sensing network for EeB will be a flexible, cheap and easily adaptable acoustic and multi- sensing prototype system for buildings composed of a configurable network of wired microphones and acoustic processing units (APU) that processes and transfer the ambient sounds in big spaces. It can be combined with other environmental sensors providing variables to be managed and transited to a central BEMO server that will also collect the discriminated levels of occupancy from the distributed APUs. Additionally, an Acoustic Processing Server (APS) will handle unknown sounds in order to improve the quality of occupancy detection. This relevant occupancy parameter, integrated with the measurement of environmental variables and conditioning controls, will help to optimize the BEM strategies and systems. Furthermore, the system allows the development of basic alert/alarm messaging for support maintenance, control and potentially security of the buildings. Acoustic sensing and processing in large spaces and open environments can provide near real-time information about the estimated occupancy level in typical areas, e.g. lobby, hall, office room, cinema, auditory, car park, corridor, or shop. Like humans' audition, microphone arrays together with appropriate pre-processing are able to reduce noises and interferences as a prerequisite for an succeeding acoustic event detection (AED). As a result this AED delivers numerical levels of occupancy or semantic tags, such as ”nobody is here now” or “a vehicle is coming here now” to the subsequent S4ECoB components. The system has to be sensitive in big environments with high background noise and reverberation regardless of the actual direction of arrival of the monitored sounds.

The main functionalities of the acoustic processing system are:

- Functional and adaptable algorithm that detects degrees of occupancy in different types of inside/outside areas and transfers these parameters to the BEM system for optimization;
- Learning and retraining functionality based on semi-automatic approaches and online data repositories;
- The audio system will be based on a HW/SW platform easily adaptable and scalable to diverse buildings and spaces and, moreover, connected and compatible to the BEM system installed.

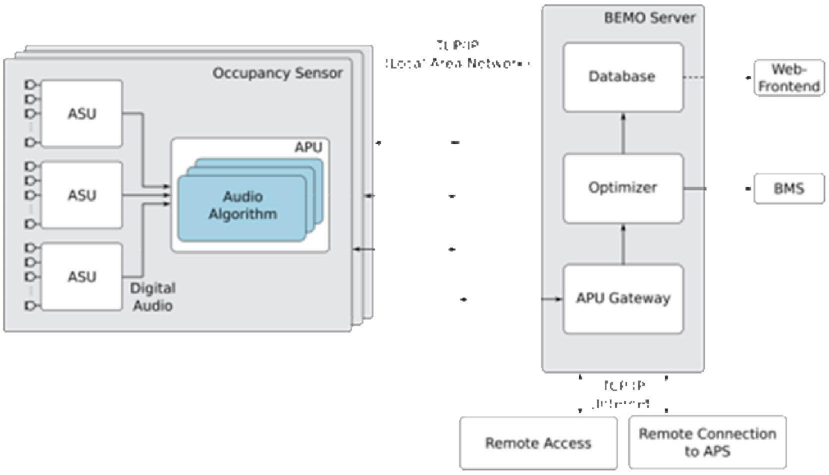


Figure 2. Audio-System Architecture of the Acoustic Processing system

3. Project pilot sites: Maremagnum shopping centre (Barcelona, Spain)

Figure 3. Maremagnum Shopping Centre (Barcelona, Spain)

Existent HVAC system in the centre

Water loop heat pump system has been utilized in the HVAC industry for many decades. The saving potential of this type of system is huge. However, there are still many unsolved problems, such as high loop energy consumption, low heat pump efficiency and high electricity cost due to improper operation.

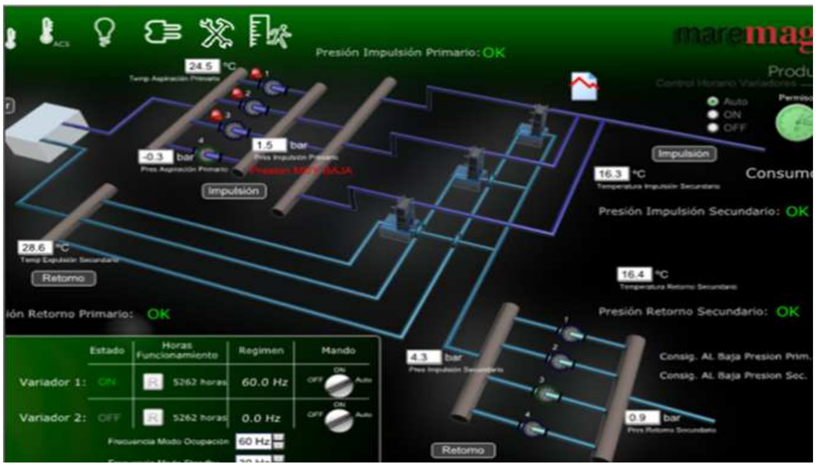
In this kind of system, multiple heat pumps are hydronically connected with a common closed water loop that circulates usually 15 to 30ºC water through the building. More often than not auxiliary cooling devices such as cooling towers (sea water heat exchanger in this case, see

Figure ***4***) are installed and they are turned on when the balance between heat pumps is insufficient to meet the load requirement. In this particular case, cooling is the most demanding regime, by far.

This mentioned system is composed by two loops:

- The primary loop is a sea water open circuit where water is drawn from the sea by means of pumps that move the water through the heat exchangers (3 heat exchangers in parallel, see
- Figure ***4***) and throw it back to the sea.
- The secondary loop is a regular water closed circuit, to which the heat pumps of the shops are connected. These heat pumps are water source heat pumps.

In the following scheme the operation is shown:



Presión Impulsión Primario: OK

ión Retorno Primario: OK

Presión Impulsión Secundario: OK

Presión Retorno Secundario: OK

● Auto
○ ON
○ OFF

	Estado	Horas Funcionamiento	Regimen	Mando
Variador 1:	ON	R 5262 horas	60.0 Hz	OFF ON Auto
Variador 2:	OFF	R 5262 horas	0.0 Hz	OFF ON Auto

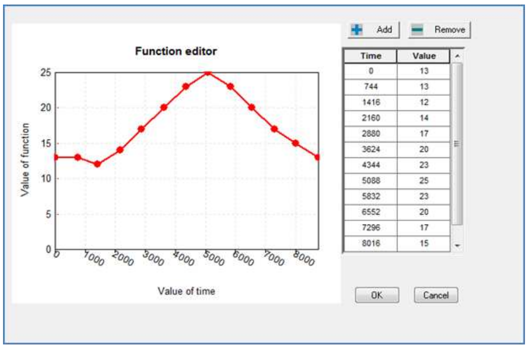
Frecuencia Modo Ocupación 60 Hz

Figure 4. Screenshoot of Maremagnum's BMS system

Estimation of a realistic baseline

An estimation of the actual energy consumption was needed, as there were no specific energy meters for this particular system. After obtaining it, this consumption will be used as a baseline to calculate the energy savings that will be achieved after carrying out the optimization strategies. The baseline consumption was calculated by taking into account all the system characteristics and some onsite spot measurements. When other data were necessary, assumption were made. As an example, the following temperature profile was implemented for representing the sea water temperature in Barcelona (see

Figure 5).



Time	Value
0	13
744	13
1416	12
2160	14
2880	17
3624	20
4344	23
5088	25
5832	23
6552	20
7296	17
8016	15

Figure 5. Estimated sea water temperature in Barcelona

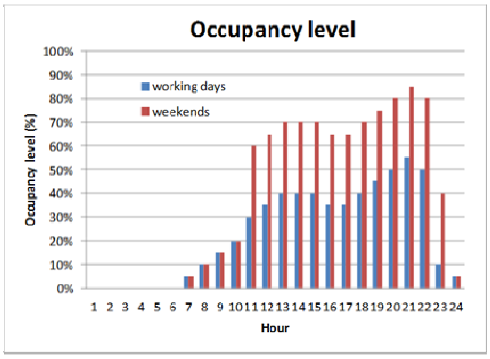


Figure 6. Occupancy level implemented in the simulation

In order to provide realistic heat gains (sensible and latent), the following occupancy profiles were implemented in the simulation (see**¡Error! No se encuentra el origen de la referencia.**).

As the cooling demand of the system is by far, the most important one, the analysis will just analyse this regime (see

Figure 8). It should be noticed that the baseline considers a working period of 10:00 to 22:00 hours, every day from March to November. One pump is working at each circuit at that time.

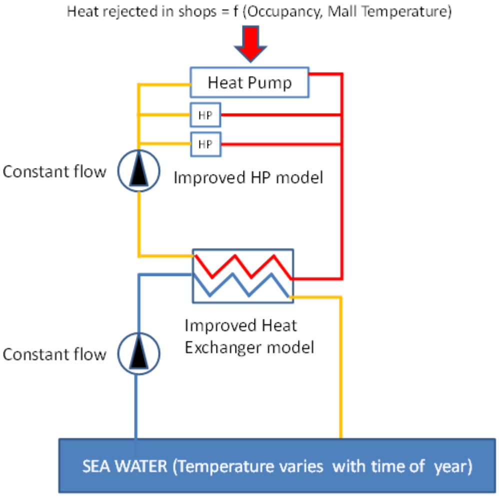


Figure 7. Baseline simulation / Maremagnum

By using the outside air as the approximated open mall temperature, and the realistic occupancy data just assumed, an estimation of the heat pump load was done for each hour, in the simulation. As the pumps work at constant flow rate all the year, only the heat pumps performance (COP) will be affected with time of year, because of the different water temperature supplied at each time. In the figure below, the obtained outcomes of this mentioned simulation are presented (see

Figure 8):

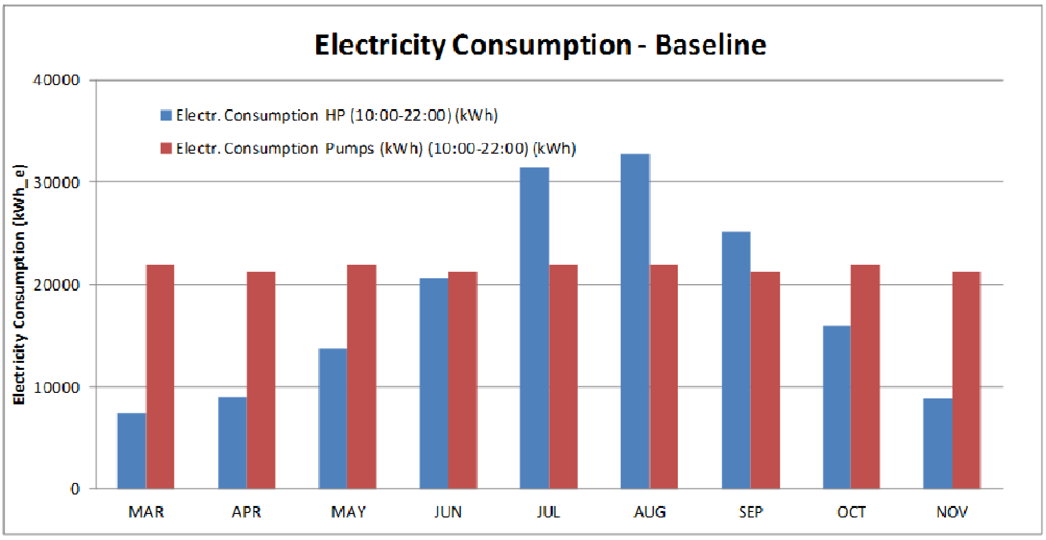


Figure 8. Predicted baseline consumption / Maremagnum

Optimization by using VFD for controlling secondary loop pumps

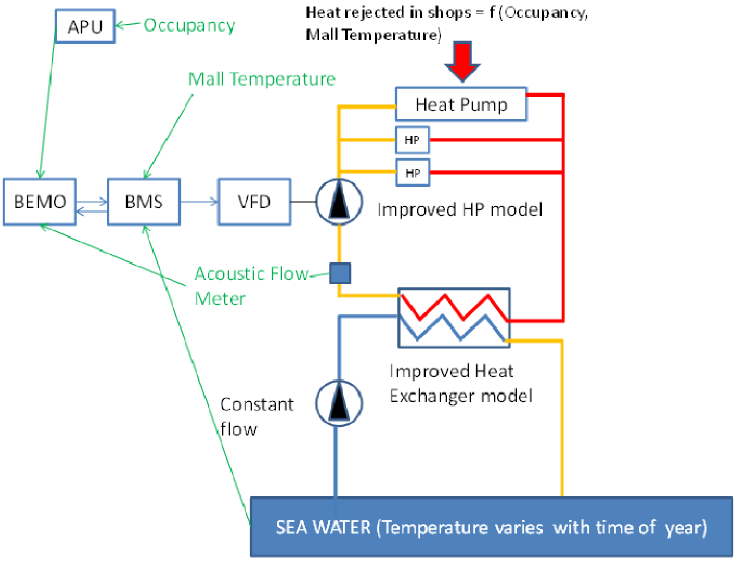


Figure 9. Optimized case / Maremagnum

The optimized system will estimate the heat released to the water loop as a function of:

- Occupancy level (measured with acoustic sensors)
- Ambient/open air mall temperature (an already recorded variable)

Of course every shop is different but what can be said is that the total amount of heat released to the condensing loop will strongly depend on the mall temperature and the occupation level. The following correlation has been estimated for Maremagnum shopping mall.

Table 1. Estimated heat pump cooling load as a function of Mall Temperature and Occupancy Level / Maremagnum

HEAT PUMPS LOAD (%)	Mall Temperature (ºC)								
Occupancy level	15	17	19	21	23	25	27	29	31
1	11.4%	15.9%	21.4%	28.1%	35.8%	44.6%	54.4%	65.3%	77.3%
2	22.7%	27.2%	32.8%	39.4%	47.1%	55.9%	65.8%	76.7%	88.7%
3	34.1%	38.6%	44.1%	50.8%	58.5%	67.3%	77.1%	88.0%	100.0%

It is very important to notice that this is just a realistic correlation between mall temperature, occupancy level and heat pump load. The final one has to be found by using experimental data. However, these realistic numbers can be useful in order to estimate the energy savings that can be obtained when using this strategy instead of the conventional one.

Once the heat released by the heat pumps was estimated and the sea water temperature is measured, the specific flow rate that minimize the total energy consumption will be obtained from the matrix of operation points (see Table 2).

Table 2. Optimized strategy (VFD in secondary) / Maremagnum

% of Nominal Flow Rate (closed loop)	Sea water Temperature (ºC)				
HP load	12	15.25	18.5	21.75	25
20%	40%	41%	42%	43%	45%
40%	46%	48%	49%	51%	52%
60%	51%	52%	54%	56%	57%
80%	54%	56%	57%	59%	61%
100%	57%	58%	60%	62%	64%

This optimized system consumes less energy although pumping less water in the secondary circuit diminishes the COP of the heat pumps. The reason is that the reduction in pumping power can compensate by far this effect. Other factors to take into account are the sea water temperature and the dependence of the heat exchanger efficiency on the water flow rates. All these considerations were taken into account when calculating the matrix of operation points.

Once the optimum flow rate has been calculated, the BMS system will vary the angular velocity of the secondary loop pump until the desired flow rate (measured with the non-intrusive acoustic flow meter) is reached.

The optimized strategy has been simulated, achieving a global energy saving of 25.5% when compared to the conventional strategy (see

Figure 10). This number cannot be directly extrapolated to the real facility until additional experimental measurements are available; however it is a good sign of potential energy savings.

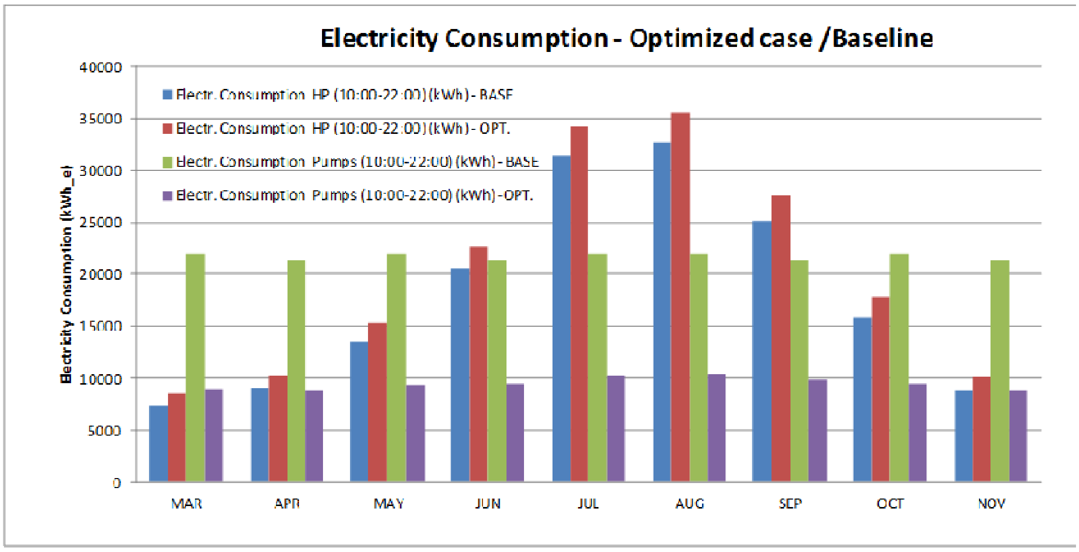


Figure 10. Predicted optimized case and baseline consumption / Maremagnum

Optimization of the lighting system

As it can be observed in the results, the implementation of the lighting optimization strategy based on occupancy control reduces approximately 16000 kWh/year the electricity consumption of the project test area. This represents the 18.3% of the annual electricity consumption of the test zone. It is important to notice that the test area is located just in one floor. Therefore it is expected that the implementation of this lighting acoustic control over the whole lighting system of the centre will produce remarkable savings in the annual electricity bill.

The obtained outcomes of this section were reached without any choice to reconfigure the lighting circuits' distribution of the test area. This means that there was no possibility to reconfigure the existent lighting circuits' configuration according to the characteristics and operational schedules of the spaces to be illuminated. An optimal reconfiguration of the lighting circuits would allow their clustering according to the characteristics of the spaces to be illuminated and consequently the adjustment of their operational schedules. It is expected that the outcomes obtained through the implementation of this suggested reconfiguration would represent a higher reduction of the annual lighting electrical consumption. This optimal configuration would also enable to perform future modifications of the lighting circuits much more easily.

In case there were not subjective lighting restrictions, this would allow a mayor illuminance uniformity over the spaces to be illuminated, keeping a more homogeneous luminous flux along the cores of the test area. This new scenario would entail the modification of the existent lighting systems in some spaces, therefore decreasing the total annual lighting electricity consumption of the test area.

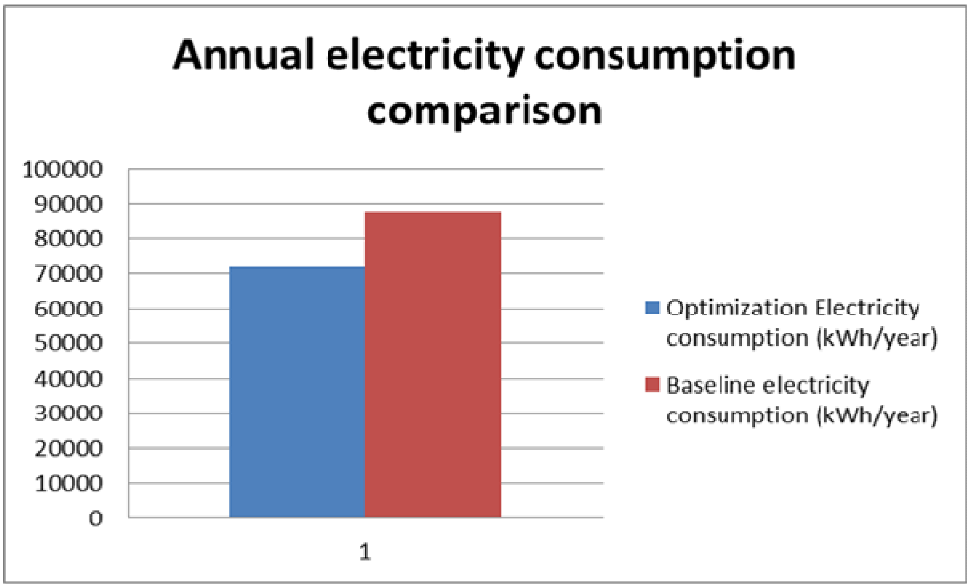


Figure 11. Annual electricity consumption / Maremagnum

4. Project pilot sites: Príncipe Pío shopping centre (Madrid, Spain)

Figure 12. Príncipe Pío Shopping Centre (Mardid, Spain)

Existent HVAC system in the centre

This section is focused in the HVAC system of the New Building of Príncipe Pío shopping mall, located in Paseo de la Florida, Madrid, adjacent to the railway station of the same name. This mentined building is connected to the rest of the shopping centre through a common hall called Node through which a big public common area (mall) is established along the shopping centre. It should be noticed that each one of the buildings that compose this public common area has each own HVAC systems.

This target building is aimed to enlarge the existing shopping mall towards the West and all its floors are intended to harbour shops and leisure spaces.

Estimation of a realistic baseline

An estimation of a realistic baseline was performed taking into consideration that the mall zones are thermally conditioned by rooftops belonging to the retail manager company of the shopping centre (CORIO NV.) while each one of the harboured shops is autonomously thermally conditioned by using its own water source heat pump that rejects/absorbs heat from a condensing loop pipe. A total of nine zones have been drawn in SketchUp and simulated although the target zones are the mall zones. Mall zones have been chosen because:

- The mall zones belong to the retail manager (CORIO)
- Their associated HVAC systems are connected to the BMS.
- The acoustic measurements performed in the mall zones have been positive.

The rest of the zones were implemented in the simulation to provide suitable boundary conditions for the calculus of the consumption of the mall zones.

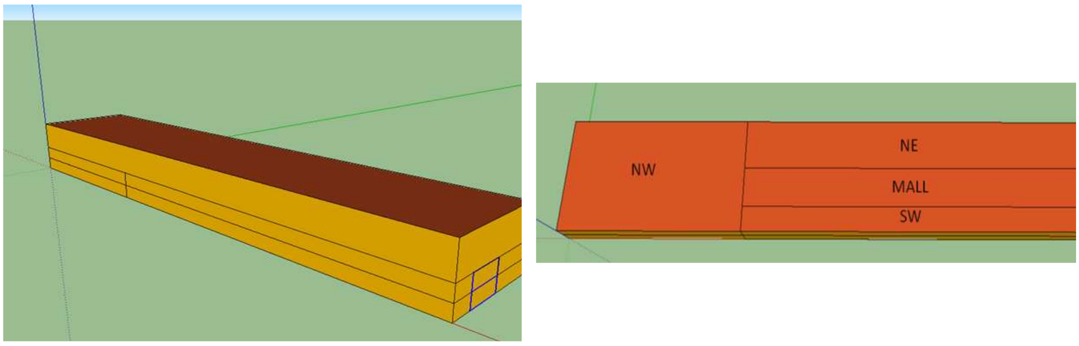


Figure 13. 3D zoning in SketchUp

The make-up air for the ventilation of the mall is taken by the 2 rooftop units that provide heating and cooling to the mall of the New Building.

The air intakes for the ventilation of the shops are located on the building facade, where a duct connects the autonomous heat pump of each shop with a ventilation grille located on the facade.

In anticipation that some shops did not install an outside air intake, the make-up flow introduced in the mall by the rooftop units has been increased. In this way these shops can take air from the mall to compensate the air that is being extracted.

All the shops (ventilation), public toilets and shop toilets (air extraction) are connected to ducts that draw air from these places to guarantee a proper air flow inside the building.

Table 3. Occupation, ventilation and air extraction rate / Príncipe Pío

NEW BUILDING				
BUILDING SECTOR	AREA (m^2)	OCCUPANCY (people)	VENTILATION RATE (m^3/h)	AIR EXTRACTION RATE (m^3/h)
BASEMENT (-1) NE ZONE	1656	346	12442	3400
BASEMENT (-1) NW ZONE	1814	259	9329	1800
BASEMENT (-1) SW ZONE	816	226	8146	2500
BASEMENT (-1) MALL	1300	260	4680	1500
BASEMENT (-1) TOTAL	**5586**	**1091**	**34597**	**9200**
GROUND FLOOR (0) NE ZONE (FASHION)	938	283	10185	2300
GROUND FLOOR (0) NE ZONE (RESTAURANT)	184	123	4426	600
GROUND FLOOR (0) NW ZONE	1711	244	8797	1600
GROUND FLOOR (0) SW ZONE	476	159	5718	1300
GROUND FLOOR (0) MALL	1300	433	4680	1500
GROUND FLOOR (0) TOTAL	**4609**	**1242**	**33806**	**7300**
NEW BUILDING TOTAL	***10195***	***2333***	***68403***	***16500***

In the simulation, it was considered that every shop has a direct entrance of outside air to compensate the ventilation and extraction rate. This air renovation will only take place from 10:00 to 22:00 hours, that is the fan schedule.

As previously mentioned, the mall will receive make-up air by means of the rooftop units. These rooftop units are able to operate with 100% outside air if it is interesting from the thermal point of view, so the amount of fresh air will not be constant.

An additional constant infiltration rate of 0.25 air changes per hour was implemented in the zones in order to take into account the unintentional or accidental introduction of outside air into the building. This is typically due to cracks in the building envelope and doors for passage.

In order to provide realistic heat gains (sensible and latent), the following occupancy profiles were implemented in the simulation.

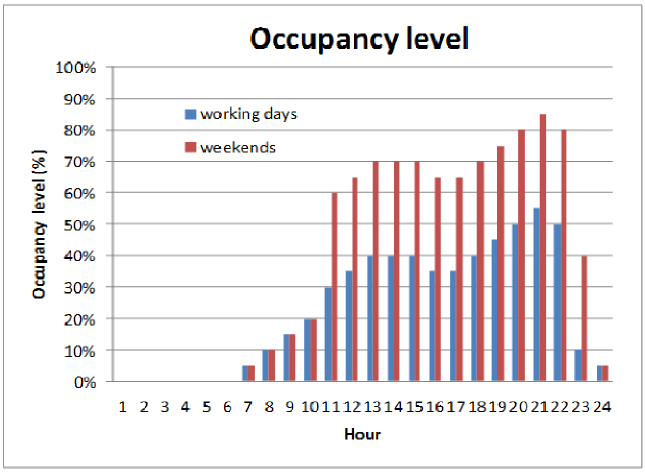


Figure 14. Occupancy level implemented in the simulation / Príncipe Pío

As it was mentioned before, the rooftop units have supply and return fans and they can work supplying 100% of outside air, when a free-cooling strategy can help to save energy. For that reason, a constant air flow was implemented in the mall zones, recirculation air and also introducing the required fresh air from outside. A simplified constant supply temperature was set up for cooling and heating in the simulation. When cooling is needed and outside air is colder than inside air, the simulation considers that the rooftops supply 100% of outside air (free-cooling).

Table 4. Rooftop technical characteristics / Príncipe Pío

	Cooling	Electrical	COP	Supply air	Return air	Makeup air
	Power (kW)	Consumption (kW)	(including fans)	flow (m3/hour)	flow (m3/hour)	flow (m3/hour)
Rooftop 1	214	88.8	2.41	29000	24400	4680
Rooftop 2	182	77.2	2.36	24500	2000	4680

Regarding the shops, each one has its own water source heat pump unit that provides heating or cooling, extracting or rejecting energy to a two pipe closed water loop controlled by CORIO. The temperature of this water loop must be kept between 15ºC and 30ºC for a proper performance of the water source heat pumps. This temperature is controlled by means of cooling towers and boilers, however the use of boilers for keeping temperature over 15ºC is infrequent. It can be said that with this system, the shop owners are paying the most part of the energy they need to keep their shop in thermal comfort, by paying the electricity consumption of the water source heat pump.

Optimization strategy

As it was previously explained, the simulations determine that the studied zones demand much more cooling than heating. This is a normal behaviour for internal zones, surrounded by thermal zones that are thermally conditioned and with considerable internal gains, generally due to people and lighting.

The HVAC system installed for these two zones, are two autonomous air-cooled rooftop air handling units (one per zone) that integrate a heat pump for the production of cool air that is delivered to the zones. The temperature of the flow is regulated according to the return air temperature and the thermostat set point. The air flow is always constant. There are many functions that could be activated in the rooftop by means of the BMS, however modifying the thermostat set points in order to follow the chosen strategy seems to be a good strategy from the energy point of view and it is likely to be accepted by the owner of the mall.

The optimization strategy A is a simple strategy that keeps the usual thermostat set points for cooling when occupancy is medium-high (occupancy levels 2 and 3) and decreases the thermal comfort when occupancy is low (occupancy level 1).

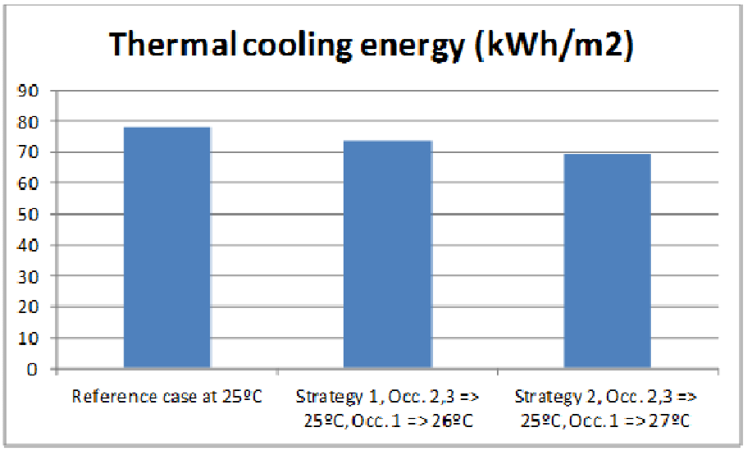


Figure 15. Optimization results (1) / Príncipe Pío

Energy savings are achieved by following this strategy that also decreases the thermal comfort of the people inside the building. However as the system provide less comfort only when the occupancy level is low, the total increment of thermally dissatisfied people is rather low too. (e.g. 5.9% energy savings for and increment of PPD of 2.3% were obtained for one specific strategy).

The optimization strategy B was a strategy based on anticipating the effect of a change in the occupation level.

It can be seen in the simulations that although when a sudden increase in occupancy happens the cooling peak due to occupation (cooling power with occupancy minus cooling power when the building is empty) is produced some time later (1-2 hours). An occupancy sensor can allow the HVAC system to react before the occupation affects the building load. Optimization strategy B was aimed to provide an anticipated response to the occupancy level change.

However, it has been estimated that providing a faster response does not save energy neither reduces the peak load in a significant way. This is the reason why optimization strategy C was created.

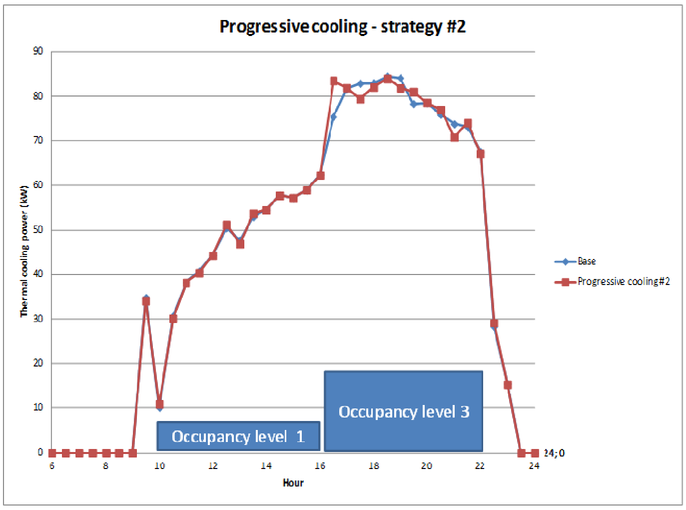


Figure 16. Average hourly total thermal cooling load for the zone FM1 in August, for an occupation pattern 1=>3 changing at 16:00. Conventional behaviour (base) vs. strategy progressive cooling

Optimization strategy C is based on strategy B, but the pre-cooling starts before the maximum occupancy level of the particular day is reached. Therefore, for this strategy, a day before occupancy forecast is needed. This can be done obtaining a pattern from the historical occupancy data registered.

In this way, the HVAC system would start providing more cooling than usual while the occupancy level is lower than the maximum expected. Therefore, the system will overcool the building to prepare it for the maximum occupancy. When the occupancy sensor detects the maximum occupancy foreseen for that day, the cooling will be adjusted to the maximum cooling set point allowed (25-26ºC) progressively, and the peak load will be smaller than it is with the conventional control.

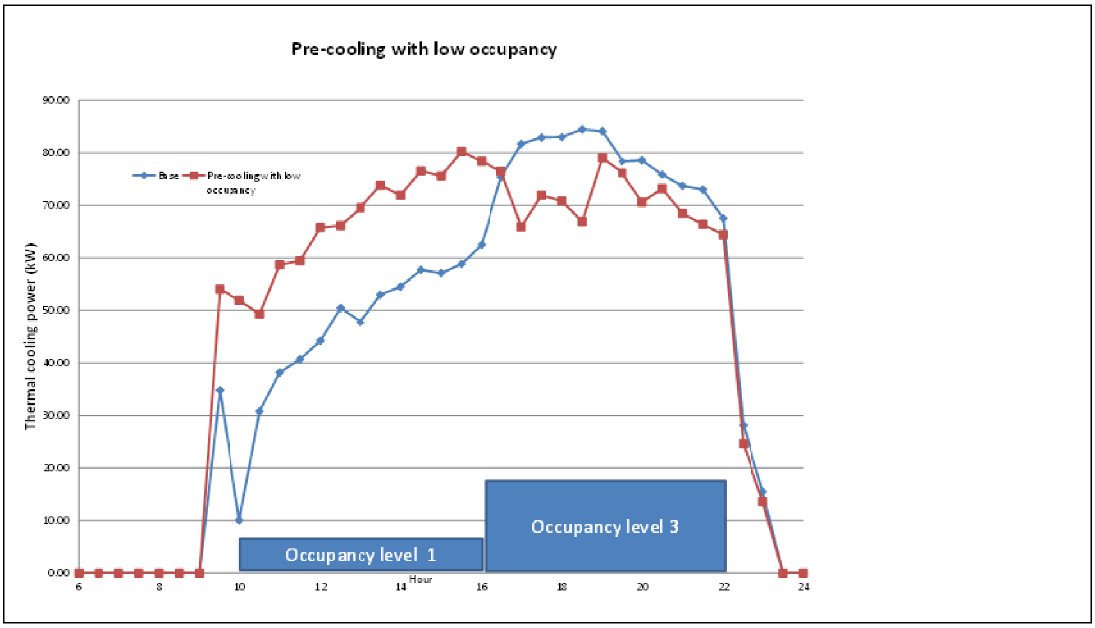


Figure 17. Average hourly total thermal cooling load for the zone FM1 in August, for an occupation pattern 1=>3 changing at 16:00. Conventional behaviour (base) vs. Pre-cooling with low occupancy

The philosophy of the strategy can be summarized in the following table (the final values in the table will have to be tuned up on site):

Table 5. Philosophy of the optimization strategy C (cooling set point as a function of occupancy)

	Maximum Occupancy Level Foreseen for the day					
	1		2		3	
Present Occupancy level	Max. Occup. not yet reached	Max. Occup. already reached	Max. Occup. not yet reached	Max. Occup. already reached	Max. Occup. not yet reached	alr
1	xxxxxxxxxxxx	25	24.5	25	24	
2	xxxxxxxxxxxx	xxxxxxxxxxxx	xxxxxxxxxxxx	25	24.5	
3	xxxxxxxxxxxx	xxxxxxxxxxxx	xxxxxxxxxxxx	xxxxxxxxxxxx	xxxxxxxxxxxx	

After implementing this strategy in the simulation, it can be said that:

- This strategy can reduce the peak demand of cooling. (it provided a significant reduction of the peak demand of 5.1% in one of the simulations). Demanding less peak power is interesting in terms of grid reliability, CO_2 emissions associated to peak hours, but also from an economic point of view as high power peaks mean the need for more electrical power contracted, which in turns leads to more fixed operation cost and inefficient use of the electrical installations. It could be a strategy to be used only during the month(s) when the peak loads are higher (July, August), to diminish the electrical power contracted.

- The total amount of energy consumed by using this strategy is higher than in the base case (a 12.1% increment was obtained for this particular simulation). However, it has to be said that the increment of consumption occurs in valley time, when electricity can be cheaper (depending on the kind of electricity contract). Also, pre-cooling periods do not usually coincide with the highest outside temperatures, so the efficiency of the heat pumps is expected to be higher in pre-cooling periods and at the same time, less cooling will be needed at the peak time, when cooling performance is usually lower.
- With this strategy, thermal comfort is generally increased in low-medium occupancy periods, when the building is slightly overcooled (e.g. reaching 24ºC, 24.5ºC) before the peak occupation of the day (e.g. 25ºC for full occupancy).

5. Conclusions

As it has been stated along the previous pages of this document, the implementation of the S4ECoB technology into the shopping centres of Madrid and Barcelona would suppose appreciable energy savings in the yearly operation of the existent shopping centres' equipment.

These mentioned energy savings would reach 25.5% of the annual electricity consumption of the systems (pumps + heat pumps) located in Maremagnum shopping centre. Which would represent over 14.030 €/year (taking into consideration an average electricity price of 0,153 €/kWh) and a payback period over 2.6 years. It should be noticed that this payback period has been estimated taking into account unofficial information from different BMS suppliers. In addition, the optimization of the lighting system in the test floor of the centre would suppose a reduction above 16000 kWh/year in the electricity consumption of this area, which represents approximately 18.3% of the annual electricity consumption of this metioned floor.

After analysing the outcomes of the three implemented control strategies in Príncipe Pío shopping centre, the selected control strategy was the third one (strategy C). This strategy would suppose an increment of 12.1% of the total energy consumption of the centre in valley time and a reduction of 5.1% of the cooling peak demand, allowing in this manner the reduction of the electrical power contract. It should be noticed that this selected strategy would suppose as well an increase of the thermal comfort in low-medium occupancy periods, when the building is slightly overcooled.

6. References

This section has been split in two different parts in order to differentiate the inputs from the project foreground and the inputs from external literature:

- Inputs from project foreground:

  This project is being developed within the seven framework programme of the European Commission. Due to confidentiality agreements reached with the

European Commision, it is not possible to reference the specific inputs from other project deliverables. For further information about the project, visit the following website: http://www.s4ecob.eu/

- Inputs from external literature:
    - ASHRAE Handbook—Fundamentals
    - Manual de Aire Acondicionado - Carrier

Optimized control strategies for a typical water loop heat pump system.

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