THE SUSTAINABLE PROJECT OF A MODEL SUPERMARKET FROM DESIGN TO OPERATION

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Fig 1: the new supermarket and its public spaces

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

Research summary

This paper describes the innovative and successful case of a new model supermarket designed, built and operated in strict compliance with sustainability principles, showing how a commercial investment can be the occasion for a wider process of urban regeneration.

A structured process was developed with the following main phases: new criteria were defined to evaluate energy and environmental quality of food retail stores; clear and measurable targets for energy and resource savings were set in advance; the actual supermarket was designed and built; performances were checked and adjusted during three years of activity through a building automation and control system.

In coherence with the local context, the project addressed sustainability issues with a comprehensive approach. The result has been not only the creation of a neighbourhood supermarket with outstanding performances in energy efficiency and comfort, but also the redevelopment of a blighted urban area into an attractive centre with public spaces and pedestrian and bicycle paths, as well as the stimulus for customers and employees to learn and adopt environmentally friendly behaviours.

An accurate and systematic control of measurable parameters proves that the actual performances fully confirm what expected: in particular gross energy needs, including food refrigeration, are 46% lower compared to an existing ordinary supermarket having the same size, in the same climate.

This project is not supposed to be a unique instance, but it’s just a paradigm for others to be designed with the same criteria, applying customised solutions to specific local features.

Keywords: urban regeneration, thermal comfort, bioclimatic approach, sustainable supermarket, energy efficiency, Building Automation and Control System.

1. Introduction

This paper describes the most significant traits of the project of a new generation supermarket, showing a practical example of comprehensive approach to design: from settlement scale to technological scale, as well as management strategies, every choice has been aimed to achieve substantial results in sustainability and energy efficiency targets.
The new supermarket is located in Conselice, a small town in the Padan Plain (Northern Italy), in a continental-Mediterranean climate area.
An existing supermarket in a pedestrian area in the city centre was dismissed, and in order to rationalize transportation a different location was chosen for the new building: a degraded and partially abandoned area which is a crucial junction between the railway station and the historical centre. This has meant Zero Net Land Degradation and a considerable opportunity for urban regeneration: a parking area has been improved and a multifunctional public square has been created; the new plan sewed up different urban areas through the reorganization of the mobility system, safely and harmoniously integrating sidewalks, cycle lanes and driveways with the existing pathway network.
In contrast with the typical distribution of traditional supermarkets, which usually overlook a parking area, the new building faces the adjacent street, emphasising the idea of a "neighbourhood store". An ample porch (figure 2) creates an intermediate space between the inside and the outside, facilitating access on foot and by bike.
To shape the new supermarket the design addressed a large number of issues in many fields, with the goal of providing extraordinary performances in terms of comfort conditions, energy consumption, water needs, resource depletion, etc. using modern assessment techniques to compare different design choices and to validate their efficacy. Thanks to a holistic approach to complex problems where economic, social and environmental issues can find their best conciliation, the project goes beyond than simply the sum of efficient technologies.

Fig 2: the main facade porch and bicycle parking

To manage its complexity it was crucial to define in advance clear and measurable targets, which lay at the basis of design and ought to be verified during regular supermarket activity.
Objectives were set in both absolute and relative terms; these latter had necessarily to be compared with a reference benchmark (a standard supermarket having the same size, in the same climate conditions), that was theoretically defined analyzing the performances of other existing supermarkets, updated to current standards and regulations. At the same time a double check was possible

using a real benchmark, because in the town of Lavezzola, just 5 km away, there is an ordinary supermarket of the same size (1000 m²): it was monitored adjusting data in order to consider current standards and regulations affecting its energy performances.

A set of guidelines was defined to manage the process and apply the scheme to other future projects, keeping the same general targets but changing the solutions in order to adapt them to local conditions.

Moreover, to define energy efficiency goals was essential to estimate the feasibility of different investments: the expected payback period was calculated over ten years, accordingly with the social and environmental vocation of the client. The chosen return on investment is quite long compared to traditional logic of business investing, but it is perfectly suitable with the global cost approach, which assesses externalities and their social costs and benefits.

Ten years can make economically viable some sustainable solutions that do not have immediate consequences in terms of cost savings, but have long terms effects on life quality. Nonetheless, energy savings are the driving force that can support other actions, such as rainwater recovery and the use of technologies and materials chosen through Life Cycle Assessment, to reduce environmental impact in production, transportation, use and disposal.

2. Innovative strategies and technologies for energy efficiency

The new supermarket has been designed in order to reduce and optimize management costs related to energy and water supplies as well as maintenance. This involved implementation of many innovative strategies and technologies on different levels: below we will describe some of the most significant, limiting the analysis to the sole supermarket operation.

2.1 Thermal comfort

Rethinking thermal comfort conditions has been a major target from which the project took shape. In ordinary supermarkets the sales area is a large container where a central, all-air system provides air conditioning trying to find the best compromise between the needs of users and employees, which may wear garments with diverse insulation values (customers' clothes are suitable for outdoor climate) and perform activities with different metabolic rates (sedentary work at check-out, walking pushing a shopping cart, handling weights, etc.).

These arguments led to rethink the targets for thermal comfort by identifying zones with different usage patterns, according to adaptive model principles, to provide tailored well-being conditions to both customers and workers. Such preliminary research influenced the following decisions.

2.2 Bioclimatic design

The building design was optimized in relation to bioclimatic principles, managing the sol-air impact in relation to the different orientations at the settlement scale.

Beginning from the early stages, sun path diagrams and "solar views" were used to thoroughly analyze the building and to define the appropriate system of windows and shading devices, in order to manage solar access and light penetration.

The main façade with its large windows, the entrance and the exit face the city street, to the west: this creates a visual connection between outside and inside, essential to the visual comfort of the check-out assistants, but

also requires the need to limit the overheating risk in summer. The project responds this issue with a system of fixed and mobile solar shadings: a large porch, a row of deciduous trees along the road and movable external tents.
The southern walls enclose the stockroom and some service rooms, which act as a thermal buffer between the external environment and the sales area; they are shielded from summer solar radiation by an overhanging roof.
The various processing areas are east-facing, taking advantage of high levels of natural light in the morning, when these rooms are affected by the maximum activity level. The direct solar radiation is controlled by external venetian blinds, which can also reduce glare. The eastern side is used for loading and unloading operations because it looks towards a railway, away from housings, and it is not visible from the road: such arrangement reduces the acoustic and visual impacts.

Fig 3: the new public space

The building closes itself off from the north with an ample and uniform wall, to reduce heat losses in winter and to create a background surface to the new public square which is part of the urban renewal related to the project (figure 3).
The roof is protected from summer overheating by a “cool roof” certified coating: it reflects the most part of incident solar radiation and efficiently re-irradiates the absorbed quota, so the cooling load inside is greatly reduced.
To guarantee an effective control of the entering light and solar radiation, tubular daylighting guidance systems are used in place of ordinary skylights to let natural light in the sales area and to moderate the solar heat load. (CIE, 2012). All the light sources are designed in order to allow high levels of diffused natural light inside the building, carefully avoiding direct light.

2.3 Integration of natural and artificial light
The rethinking of comfort targets, as the project starting point, also included the visual comfort. The appropriate illuminance levels are closely related to both visual task needs and commercial requirements. It is possible to reduce the artificial illumination levels when the following aspects are considered: the relationship among the differently lighted areas within the field of view, the focus on the products and the negligible improvement in visual performance when the illuminance level goes beyond a certain limit (Weston, 1953).
The project maximizes the use of natural light through the abovementioned systems of zenithal lighting from the tubular daylighting devices, evenly distributed over the shelves and above some workspaces. The number and the size of that devices was accurately designed, also through software raytracing tools such as LBNL Radiance, to assure controlled light levels on the vertical plane and to develop strategies for integration of artificial light, in order to always achieve the correct lighting levels on the merchandise.
The linear fluorescent lamps on the shelves and the aisles can electronically modulate their luminous flux in relation to natural illuminance levels. Display cases and counters are

specifically lighted with LED lamps. Inside the stockroom and the processing areas, fluorescent lamps are step controlled accordingly with the availability of natural light.

2.4 Building envelope

The building envelope is made with local materials and inexpensive traditional technologies. The structure is composed by steel columns and laminated wood beams, supporting sandwich panels insulated with mineral wool, which make the shed roof; walls are formed by blocks of lightweight concrete with external insulation.

The will to attain the "A" class energy efficiency, was crucial for its great communicative impact, but as a matter of fact the energy class only pertains to primary energy demand for winter heating and ventilation, and hot water production, which in reality are just a fraction of the total energy need of the supermarket. In addition, the theoretical energy need does not correspond to the actual energy use, mainly because standardized methods refer to usage patterns that differ from the real ones (Majcen, Itard & Visscher 2013).

The envelope design was based on a realistic and complete assessment of the annual energy balance: energy simulations were carried out under hourly dynamic conditions with EnergyPlus software, using the most adherent usage pattern and local climatic data. Such simulations, including the HVAC system features, led to scientific based predictions of expected energy demand, disaggregated by services and zones. That was crucial to compare different design choices and to meet the set targets.

2.5 HVAC plant

The previous considerations about thermal comfort imply a system that has to meet the different well-being needs through integrated solutions: active, hybrid and passive strategies and technologies to control the thermal environment are implemented in relation with the typical Mediterranean climate features and its varying conditions from summer to winter.

A double heating and cooling system has been the answer to the dual need to provide comfort both to customers and clerks. A central, all-air system supplies ventilation and an essential level of air-conditioning in the sales area, while a radiant heating and cooling system give a "thermal correction" to the workplaces. The double system, which obviously increases installation costs, is justified by the global cost-benefit analysis, since it produces significant reduction of energy consumption while improving environmental performance.

Renewable energy is largely used through a 30 kWp photovoltaic pergola which shades a small parking lot, an air heat pump, a ground heat pump, free cooling and earth air cooling systems.

The all-air system is equipped with a rooftop packaged unit, with thermodynamic recovery of energy from exhaust air: it satisfies all the ventilation and dehumidification needs, and it produces a basic level of temperature control, suitable for the customers comfort in the sales area. Average temperature is kept at about 18°C in winter, while in summer it slides based on the outside temperature: according to adaptive comfort model, it is allowed a relative variability of the set-point, since the perceptions of supermarket customers are immediately related to the outdoor climate, and they are closely linked to a changing climatic situation.

The set point is calculated starting from the following formula, suitable for naturally ventilated buildings (Brager & de Dear, 2000), adapted during testing, adjusting and balancing (TAB) activities in accordance with the building thermal response:

$T_{operating} = 18.9 + (0.255 \cdot T_{outside\ air})$

The formula implies that the air temperature is not sufficient to represent thermal comfort conditions, and to better appreciate the effects of radiative heat exchange it is more appropriate to control the operating temperature.

The radiant hydronic system uses a geothermal heat pump with four vertical probes (90 m depth) to create specific controlled thermal zones in workplace areas. For example over the check-out counters radiant ceiling panels give fast response to changing thermal conditions (considering that they are subject to the effects of the big west windows) and effectively keep the operative temperature set point thanks to their low thermal inertia; the ceiling solution gives a better view factor than a radiant floor, and it works better in cooling taking advantage of the air convective movements; lightweight micro-perforated panels have been chosen for architectural integration and sound absorption improvement.

2.6 Air quality control

Besides the global air temperature, two more parameters, air humidity and CO2, are controlled by the all-air system.

In traditional supermarkets, open refrigerated counters indirectly provides to abate the air moisture: it forms frost and it is removed by repeated defrost cycles; this process is energy consuming but the cost is charged on the food refrigeration service. Active dehumidification by the HVAC system is rarely a necessity.

However, in this case-study the energy saving goals required to close with glass flaps all the self-service refrigerated counters; those surfaces are colder than every other surface, and it is crucial to keep the transparency, avoiding any condensation. To control the air dew point, the rooftop reuses the condensing heat from the over-cooling to re-heat the air, providing higher efficiency levels than a traditional water fed re-heat coil.

Supplying drier air creates a mild cooling effect: this, together with the excellent performance of the building envelope in protecting from the sol-air impact, ensure adequate comfort conditions with moderately cool air temperatures. Great energy savings in cooling service testify that this system, although more articulated, can be much more efficient than a traditional one.

The all-air system can guarantee the ventilation rates as prescribed by the standards, which are based on theoretical occupancy figures. An excess of external air is not useful and requires unnecessary energy, so usually the air renewal is reduced to the essentials, which is determined with the aid of two CO2 sensors inside the sales area; the materials and the goods inside the building do not require to control other pollutants.

Several months of CO2 levels observation led to a progressive adjustment of the minimum air change rate, until the optimal level was identified, to assure air quality with as less energy as possible. The supervision system shows that this minimum level can be kept for most of the time, except in extraordinary circumstances that rarely occur; during crowded situations the concentration of carbon dioxide can exceed a threshold value set at 1000 ppm: in that case the ventilation system immediately increases the intake of outside air.

2.7 Building Automation and Control System

Since the supermarket opened, an accurate monitoring activity started, in order to check and optimize the systems, to verify the performances of the supermarket and to certify the achievement of design goals.

The activity followed the European standard

EN 16247-2 on buildings energy audits and it lasted three years, during which the operating parameters, the descriptors of the indoor environmental quality as well as the energy savings were recorded and analyzed, daily, weekly and monthly.
The supervision was used to implement predictive maintenance techniques, to identify dysfunctions and to undertake prompt actions to solve problems and to optimize the system: many times the machinery, even if operating and ensuring the expected services, do not work in the most efficient way, often consuming unnecessary energy. In this case the commissioning, together with an accurate TAB activity, have proved that significant savings can be obtained. Annual reports were produced to describe the performances to the client.

3. Conclusions

The design had expected the overall energy saving at about 40% in comparison to the benchmark: the monitoring phase has been a crucial step to verify this target.
The proximity of the supermarket in Lavezzola, built and managed with ordinary procedures, was a precious opportunity to confirm the effectiveness of the theoretical benchmark that was initially developed: in fact their performances were very similar to each other, as it can be seen in figure 4.
The actual energy saving of the new supermarket, scientifically measured during three years of monitoring activities, is 46%, which can be divided in 63% related to savings in building services (heating, cooling, ventilation, hot water, lighting) and 29% related to savings in commercial services (food refrigeration, food preparation, etc.).

The coherence between expected and actual results has not been reached by chance, but thanks to a thoroughly exhaustive design method, based on clear goals and simulations to verify design hypothesis, together with an accurate definition of the benchmark.

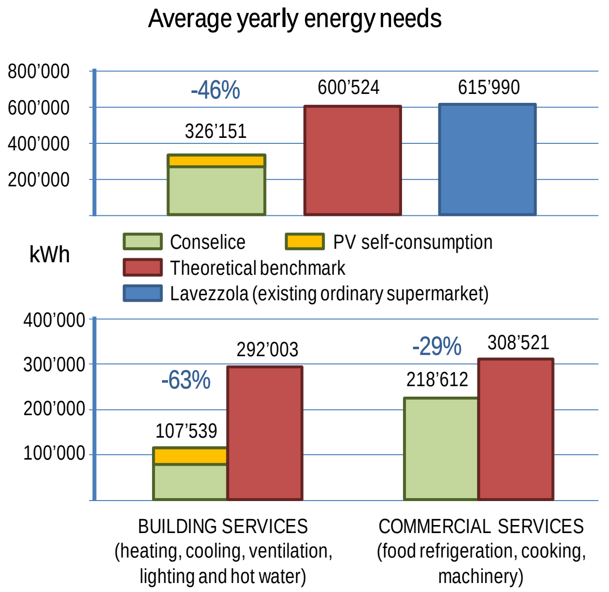

Fig 4: synthesis of measured energy performances (average of 2012, 2013, 2014)

The figures show that the best performances were achieved in the "building services", the field where designers were free to subvert habitual concepts, introducing new ideas about the comfort and technologies: in this area the upper limit has been probably reached with today's standards; further improvements can be made but have been considered not economically viable at the moment. On the contrary, the "commercial services" are strictly tied to deep-rooted habits where designers can have marginal influence. Moreover, there are some issues that need additional refinement, such as a deeper integration between food refrigeration processes and building air

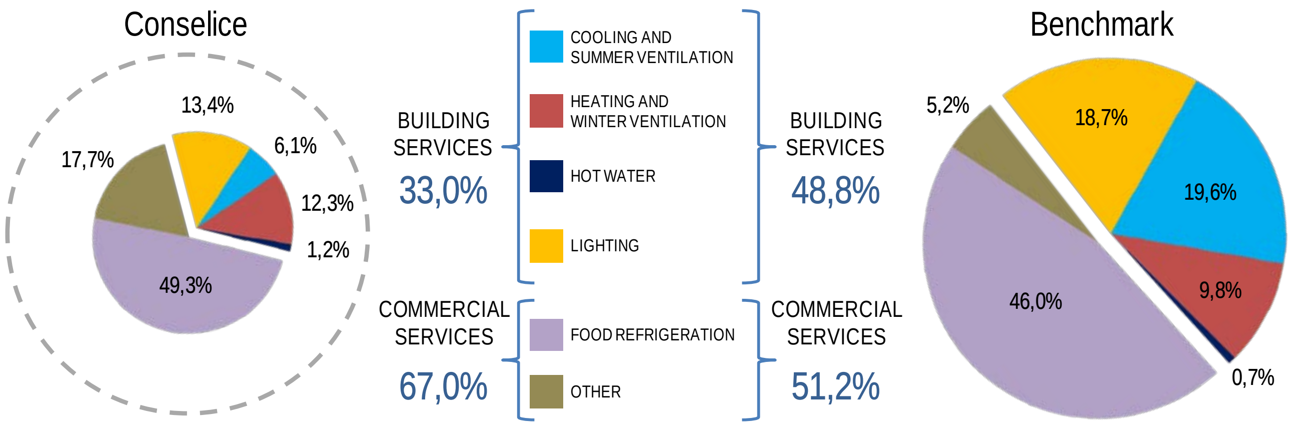

Fig 5: subdivision of energy services in the new supermarket and in the theoretical benchmark

conditioning (condensing heat recovery and management of dew formation over closed counters).

In comparison with the cost faced to build the supermarket in Lavezzola, designed to be barely compliant to law and standards, the extra investment required to implement the innovative technologies and strategies in the *new generation supermarket* was fully repaid in three years.

A manual has been prepared, based on both the design experience and the monitoring activity: it addresses the specific features of the client, owner of more than 190 super- and hyper-markets in the Adriatic region in Northeast and Central Italy, and it contains sustainability guidelines for both existing and new supermarkets. The goal is to set a comprehensive method to face the features of each new project through the best solutions for every different situation, avoiding the creation of carbon copies supermarkets.

The encouraging outcomes of the project have led the client to commission a more advanced supermarket aimed at reaching ZEB performance, taking account of the acquired knowledge and experience: it is currently under construction and it will be complete in autumn 2015.

4. Acknowledgments

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