Improving comfort and energy efficiency in a nursery school design process

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ABSTRACT: A new nursery school in Milan was designed in the framework of a national research about low-energy buildings in temperate climates.
The design of the case study started from a bioclimatic-approach, considering relationship between building envelope and sun path. In particular, orientation and morphology of the school are optimized (i.e. the building shapes improve solar control; classrooms and offices face South, services face North), the envelope is thermally efficient in both its opaque and transparent parts and overhangs are dimensioned to ensure solar gain in winter and to avoid direct solar radiation during summer season. A set of solutions for optimizing both energy efficiency and comfort conditions has been assessed. A floor radiant system, fed by a groundwater heat pump, has been foreseen and combined with a primary air ventilation system, equipped with heat recovery and managed by CO2 sensors. The school will be also equipped with opening window detectors and presence detectors, coupled by daylighting sensors, for controlling both illumination and thermal energy supply (hot water circulation in the radiant floor pipes and primary air cycle). Further, RE has been integrated in the design for hot water production by evacuated solar collectors placed on the roof of the higher block. As a result, a dynamic simulation made by VisualDOE software assessed 20 kWh/m² of energy heating demand: this value is below national standards foreseen from 2009, referring to the recent Italian implementation of the EPBD.

Conference Topic: 2. Design strategies and tools
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1. INTRODUCTION

European-continental basic principles of retaining heat in the building are based on well insulated envelope and exploiting the available solar energy. These principles are applicable also to milder climates, as in Northern Italy, but it must consider other aspects related to the building performance during mid-seasons and summer, influenced by Mediterranean climate. Therefore, a climate sensitive building in Milan should consider the following aspects:

- reducing heat loss and exploit solar energy in winter;
- being neutral in the mid-seasons, when outdoor temperature is comfortable and keeping windows open is enough to feel good inside;
- providing good shading and ventilation (protection from overheating) in summer, at least in non-extreme weather conditions, when cooling systems can be avoided.

In particular, the building envelope – and especially the transparent elements – should be able to modulate the energy and mass flow according to the season (solar gain, shading, night heat loss, ventilation, etc.). The issue of thermal storage (inertia) and its relationship to high levels of insulation in the opaque parts of the envelope is also a major issue in mild climates, as it has an impact on the time behaviour of the building.

A research funded by the Italian Ministry of University started in 2004 with the involvement of Politecnico di Milano, Università di Padova and Università di Genova. Its aim is to find some rules of thumb for low-energy small-scale buildings in Northern Italian climates, incorporating principles of sustainable design and energy efficiency into current building projects, such as dwellings and schools.

In the frame of this research, during 2005 Municipality of Milano - School Buildings Division nominated Politecnico di Milano to establish a design team for the realization of a new childhood centre that would embody the finest contemporary architecture integrated with low-energy and climate-conscious concepts.

The main design goal, from the energy point of view, was to minimizing the needs of heating during winter season and, as a consequence, extending the period of the year when the building provides indoor comfort in free running mode. The idea that drove the design was "heating the whole childhood centre by a single apartment heating plant".

2. THE SUSTAINABILITY ISSUES

Given the predicted impact of global warming on our climatic system, any measures to reduce the adverse effects must be taken into account which include:

- reduction of the consumption of fossil fuels;
- increased use of renewable resources;
- rational use of energy;
- maximizing the use of recyclable materials.

Carefully considered the previous issues, the design of the new Milan Childhood Centre evolved following primary concepts through the integration of architecture and engineering principles:

- low energy consumptions compared to common nursery schools;
- high standard of thermal and visual comfort provided to the occupants;
- high flexible and extendable spaces.

Municipality of Milano, together with Politecnico di Milano, recognized the importance of developing a flexible, efficient, aesthetically significant building, that serves the needs of families for future generations.

3. THE SITE POTENTIAL

With a site located in north-eastern Milan, the abundant underground water resources prompted early discussions with the design team about the possibility of exploiting this source for heating and cooling of the building.

A study into the underground water chart showed that both water table under the project site and a nearby canal, suitable for collecting the waste water, are available. The encouraging benefits have been clearly recognized by architects, engineers, facilities managers and building owners.

The expected advantages of using underground heat pump for heating and cooling of a building include: high performances, both in winter and, if required, in summer (reversible type, cooling mode), no urban pollution, conservation of global CO_2 emissions, active contribution in controlling the water table level and revitalization of the nearby canal.

Moreover, the exploitation of solar energy that has been included since the first design phases of the building: the adopted solar approach has determined a rotation of the foot-mark originally foreseen for the building area, for optimizing building shape in respect to the sun path.

4. INTEGRATED BUILDING DISEGN

The team moved forward with a careful investigation into the implications of designing a low energy consumption childhood centre. The issues included:

- the necessity of an integrated design approach involving the architects, mechanical engineers, structural engineers, electrical engineers and lighting designers;
- the need for an architectural language embedded with the mechanical and structural concepts: the architectural aesthetic is inextricably intertwined with the engineering decisions for minimizing energy use;
- the rational use of energy through efficient control systems in order to manage automatically the local energy supplied;
- the need to provide dynamic simulation for the prediction of the energy consumptions associated with the indoor comfort requirements;
- the necessity to carefully design the interior spaces for enhancing the cross-flow natural ventilation.

The design team sought to operate in an environment of close collaboration, challenging design assumptions across disciplines for developing a thoroughly integrated solution. In fact, this type of communication is essential to the achievement of a low energy consumption building.

4.1 Building morphology

The New Childhood Centre consists of a nursery school, a kindergarten and the associated spaces. Besides a fully independent baby-parking and amusement spaces complete the centre.

The multi-use building encloses a floor area of 1800 m^2 and is designed to accommodate 120 children in the nursery school's wing, and about 30 children in the baby-parking unit.

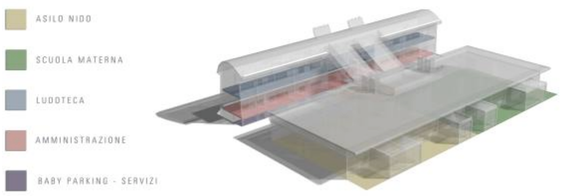

Figure 1: Three dimensional functional scheme

The Childhood Centre stretches in “H” shape, creating two inner courtyards. In order to optimize the solar heat gains during winter time, the parallel wings extends from east to west.

By combining indoor environment with open breathing spaces, the innermost part of the centre seeks to balance with the green outdoor environment.

The building incorporates a range of passive environmental design concepts, such as the south facing classrooms, greenhouses-laboratories and offices, in order to maximise heat gain from the sun during winter time, and the north oriented services (i.e. the kitchen, the laundry rooms, the dormitory areas), for reducing the unwanted solar gain.

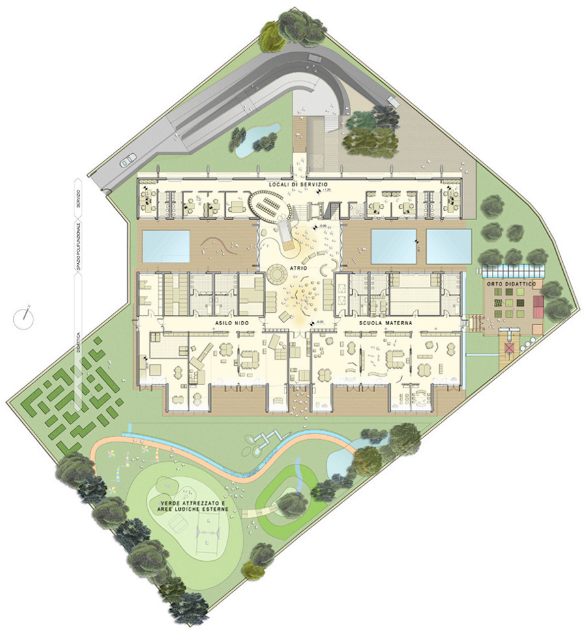

Figure 2: Ground floor plan

Figure 3: Cross section

4.2 Building envelope

While the single-layer wall (monolithic masonry) was able to satisfy the lower comfort requirements of the past centuries in Northern Italy, the increase in the expected comfort levels and the advancement of legislation in energy savings mean that, nowadays, more complex performances are required from the envelope.

Thermal resistance levels are getting higher and higher – meaning thicker layers of insulation material – while technical installation become more complex and spread into the building and other sustainability issues become more important. Among these:

- minimising the use of materials (less material for more performance);
- the more stringent requirements on waste management, both during construction and after dismantling the building, that lead to widespread recycling of building materials;
- easing the maintenance and substitution operations during the life of the building;
- minimising other forms of energy that are embodied in the finished building (transport, assembly, maintenance, dismantling): this is mainly related to the overall lightness of the technical solutions.

Considering this, in the most advanced countries there is a trend towards the use of dry-assembled layered solutions that rely on materials available on the market with specific functions. These techniques are known as "Structure/Envelope" construction (Str/En) as they separate the load-bearing structure from the other components of the building, that are assembled on independent, light sub-structures [1].

With Str/En construction, each technical solution can be designed specifically for its condition of use, varying the layers, their thickness, etc. – so it is the ideal condition for designing a climate sensitive building [2].

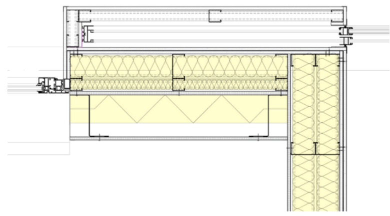

Figure 4: Detail of building envelope - section

Moreover, as the layers are generally dry-assembled on specific sub-structures, the resulting cavities can be filled with insulation and can be used for technical runs.

As a consequence of the conservative design approach, low heat waste was achieved through high–performance opaque and transparent enclosures: the U–values chosen are even lower than 25% compared to the new national standard requirements foreseen for 2009 (D.Lgs. n.192 – 2005, first national implementation of EPBD).

Table 1: Enclosures U-values adopted (comparison with the D.Lgs, n. 192 requirements)

Envelope U-value (W/m^{2}K)			
Surfaces	From 1/1/06	From 1/1/09	Childhood Centre
Opaque Vertical	< 0.46	< 0.37	< 0.28
Opaque Horizontal	< 0.43	< 0.34	< 0.26
Windows	< 2.4	< 1.9	< 1.43

For the solar control on transparent component, external overhangs prevent the unwanted solar gains during summer time, while the solar heat gains are allowed during the winter season. Moreover, the positioning of the windows and a solar chimney help in providing natural ventilation. These aspects are especially important for a public school building, where usually there is no provision for summer air conditioning.

4.3 Heating systems

Winter thermal comfort conditions are provided by a primary air ventilation system coupled with floor radiant panels. This combination minimises electricity consumption in pumps and fans. Floor radiant systems allow both for lower air temperature thus reducing energy consumption, and for high level of thermal comfort performances (optimisation of mean radiant temperature, warm floor surface particularly suitable for children).

A groundwater heat pump system supplies hot water in winter for space heating and DHW, through storage tanks.

During the rest of the year, a 20 m^2 surface of evacuated solar thermal collectors, located on the tilted south facing roof, is sufficient to provide hot water for DHW. The same solar system also contribute to hot water in storage tanks in winter.

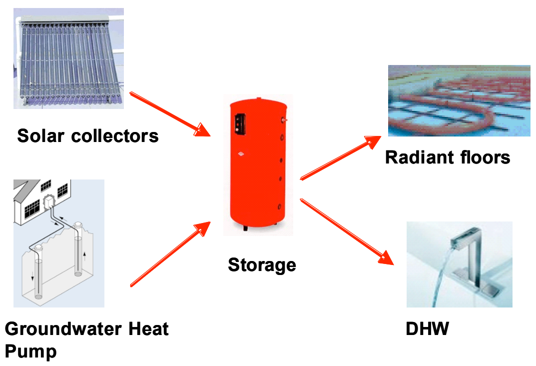

Figure 5: Concept of heating system

4.4 Control systems

Several times people unintentionally over-use the energy supplies and the effects are often significant in terms of energy wastes. Some cases are listed below.

- Activated the artificial light when required during the day, it is common to forget to turn it off even if the natural daylighting level is become adequate.
- It happens to forget to turn off lights or to leave the electric appliances in a stand-by mode after their utilization.
- The windows periodically opened to renew indoor air (especially in absence of forced ventilation system for primary air supply) is left opened more than the needed time, especially when the thermal energy supply rises to ensure the temperature set point.
- It is more instinctive to open the window instead of reducing the thermostat set point when periodically indoor temperature becomes higher (i.e. because of the increasing internal heat gain).
- Many people usually don't care to turn off the local heating or cooling energy system while going out from the apartment.

The amount of energy wastes are related, on one hand, to the carelessness of the people behaviour (in particular when any additional cost due to the higher energy consumption is not need to pay, i.e. in a public building) and, on the other hand, to the absence of any equipment dedicated to perform specific controls [3].

In view of the above points, it was decided that each space of the school will be equipped with presence detectors coupled by daylighting sensors, for controlling both the electricity and the thermal energy supply. Primary air ventilation operation mode will be also controlled by contact detectors for windows and CO_2 sensors.

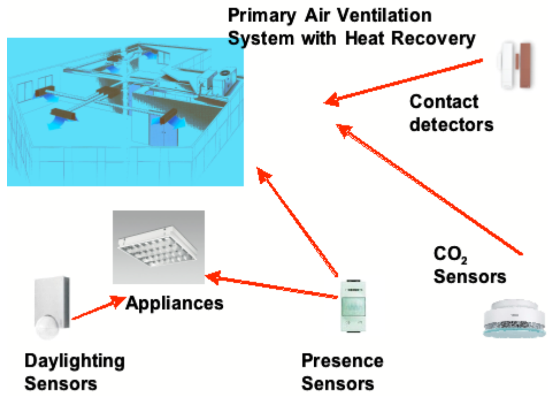

Figure 6: Concept of control systems interaction

5. THE ENERGY PERFORMANCE

Having established the design strategies, it was necessary to elaborate simulations to verify the building energy performances during the implementation phases of the project.

5.1 The simulation model

The energy strategies were evaluated using VisualDOE v. 4.1, building energy simulation software based on DOE-2 dynamic code (v. E-119) [4].

The final energy model, was resulted as a building volume divided in ten macro-thermal-zones, based on orientations, position in the building, uses, occupation periods and related HVAC systems.

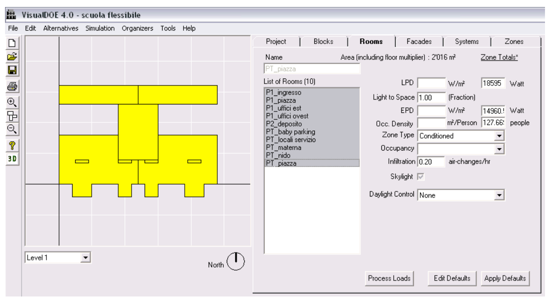

Figure 7: Building simulation model

An hydronic water loop heat pump has been assigned as system, with COP=4 and with a ground source temperature time schedule set at groundwater values (between 10 – 15°C during the whole year).

It has to be noted that in order to simulate winter energy performances considering a floor radiant system coupled with forced primary air supply, the indoor air temperature set points have been appreciatively considered two degrees lower than the conventional values (the simulation code doesn't foresee more than one system type contemporary).

The activation of electrical and thermal supply based on the presence detectors has been simulated by an appropriate set of occupancies schedules.

Moreover, the activation of the artificial lights in dimming mode, depending on the natural illumination levels, checked by the daylighting sensors (DOE-2 utility), has been assessed.

5.2 Energy and environmental performances

Electrical energy savings (30% less) due to the control systems are significant: the comparison between the two cases (conventional use of equipments and appliances and improving management with automatic control systems) for the electrical annual demand patterns are shown in the Fig. 8.

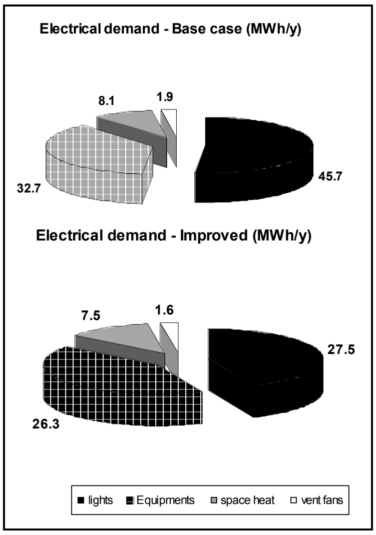

Figure 8: Electrical demand patterns - comparison

Under the thermal point of view, 20 kWh/m^2 of annual heating energy load for the building has been assessed (including 5.5 l/s per person for minimum amount of primary air flow, with an heat recovery efficiency of 70%). The monthly energy loads are reported in Fig. 9.

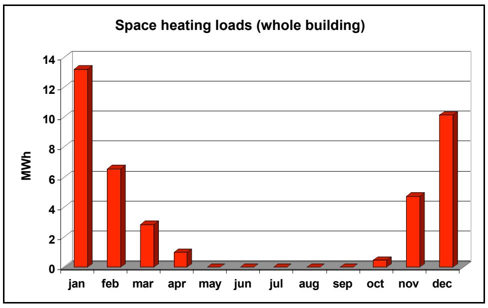

Figure 9: Monthly heating energy demand

For the entire winter season 8043 kWh of electrical energy consumptions by the groundwater heat pump has been estimated. Referring to the conventional adoption of gas boiler for heating, a reduction of 53% of primary energy (national electrical generation 39% of efficiency) and 50% of GHG emission [5] respectively can be appreciated.

Table 2: annual performance of groundwater HP in comparison to a conventional gas boiler heating system.

Heating type	Primary energy (kWh/y)	GHG (kg/y)
Gas boiler	43431	10713
HP	20623	5393

6. CONCLUSIONS

In current practices, energy efficiency should be a key issue in a building design process. To achieve this goal since the initial phase of the project an integrated design approach is necessary.

The design of the case study started considering the optimization of the building orientation and internal spaces distribution in relation to solar radiation. Efficient materials and technical solutions are considered for both the opaque and transparent surfaces of building envelope. As a consequence, in summer and mid seasons it is expected that the building should have a higher thermal comfort condition in comparison to a conventional building.

The HVAC system, consisting of floor radiant panels coupled with primary air ventilation system CO_2-controlled, provide high thermal comfort and IAQ. The adoption of heat recovery and a groundwater HP allow an appreciable amount of energy saving, as well as the management of the local energy supply through the efficient control systems.

The active solar thermal system provide, without GHG emission, hot water throughout the year, required for domestic use and partially for radiant panels.

The results of energy simulation clearly indicate that the adopted solutions for the present building design contribute appreciably in energy savings and environmental effect, for annual electrical consumption and winter heating.

The passive concepts incorporated in building design, should provide suitable comfort conditions also during summer and mid seasons. However, if required during extreme weather conditions, the HVAC system could be activated by the use of HP in reversible mode.

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