Energy-Environmental Efficiency in the Integrated Design of a School Building in Imola, Italy

M. Grosso[1], L. Raimondo[1], A. Dal Fiume[2]

[1] *Department of Human Settlements Science and Technology (DINSE)*
Polytechnic University of Turin
Viale Mattioli 39, 10125 Torino, ITALY
e-mail: mario.grosso@polito.it
[2] *Municipality of Imola, Servizio Opere Pubbliche*
Via Emilia, 147, 40026 IMOLA (BO)
e-mail: dalfiume.a@comune.imola.bo.it

ABSTRACT

The Municipality of Imola is strongly committed to environmental friendly and energy conscious policies both at urban planning level and public building design. In particular, the latest construction plan of a new junior High School building has given a chance for checking an environmentally sound and energy conscious approach on the architectural and technological design development of an educational building. HVAC systems are well integrated to RES systems such as water and air solar collectors as well as earth heat exchangers, in a highly insulated and air tight building with a ventilation heat recovery. This paper describes the main steps of the design process characterised by a deep integration between aesthetical, technological, and environmental performance options as well as the renewable energy sources-related features of the project. In addition, the contribution to the annual energy balance of the various “passive” and hybrid systems is shown as well as the energy-environmental efficiency factor as a parameter to evaluate the GWP reduction.

KEYWORDS

School, Renewable sources, Passive systems, Hybrid systems, Energy-environmental efficiency

INTRODUCTION

The current energy consumption of the 25 EU member States amounts to 1725 Mtep[1], 40% more than at the beginning of the 1970 with an increase rate of 1% per year. The building sector is responsible for the 40% of that amount (domestic end use, 17%; tertiary end use, 10%; transformation losses, 13%).

If this trend is confirmed, the gross energy demand could increase of 10% in 15 years (2005-2020), reaching 1900 Mtep (for a GNP increase of 2,4%). This scenario leads to an increase of 14% of the green gasses emission with respect to 1990, instead of decreasing as agreed upon by the Kyoto Protocol, signed by all EU member States. For this reason, a debate is developing on the need for stronger energy saving policies, by setting goals more ambitious than the ones put forward in the most recent energy efficiency Directives, among which the 2002/91/EC on

([1]) 1 Mtep = $41{,}87\times10^{6}$ = $11{,}63\times10^{6}$ MWh; data from *Green book on energy efficiency*, European Commission, DG Energy and Transport, COM(2005)265, Brussels, 2005.

Energy performance of buildings, which is expected to yield a saving of 40 Mtep by 2020, corresponding to 10,5% of the overall predicted reduction.
International bodies such as ISO and CEN are developing standards aimed at setting the framework for the evaluation of environmental performance of buildings and building products[2]. Important impact categories within these standards are the primary non-renewable and renewable energy loads as well as the related green gas emissions measured by the CO_2 equivalent unit. One way to evaluate these aspects – at national Italian level[3], for building design at the use life cycle stage – will be through a lump parameter called *energy-environmental efficiency factor* (F_{e3}): the ratio of the design estimate to a reference value for the overall primary non-renewable energy use; the reference value is related to the same building design configuration, but considering current technology applications, without eco-compatible systems and strategies, and compliance with minimum by-laws and regulations requirements. Grosso (2005).
This factor will be used within a score-based evaluation method, according to the classes shown in Table 1.

TABLE 1
Classes of values for the energy-environmental efficiency factor

CLASS	Ranges of values for F_{e3}	
	Residential buildings	Tertiary buildings
0	$F_{e3} \leq 0,00$	$F_{e3} \leq 0,00$
1	$0,00 < F_{e3} \leq 0,22$	$0,00 < F_{e3} \leq 0,19$
2	$0,22 < F_{e3} \leq 0,52$	$0,19 < F_{e3} \leq 0,53$
3	$0,52 < F_{e3} \leq 0,68$	$0,53 < F_{e3} \leq 0,67$
4	$0,68 < F_{e3} \leq 0,78$	$0,67 < F_{e3} \leq 0,80$
5	$0,78 < F_{e3}$	$0,80 < F_{e3}$

The Imola's School project reaches Class 4, including all systems described in the following paragraphs. However, aim of the project is not only energy efficiency, but also an optimal building-to-comfort behaviour, particularly important for an educational structure. Pre-disposition for installation of monitoring instruments is also part of the design development as an essential objective, considering the need to test such an innovative application of eco-compatible energy systems.

BUILDING DESIGN FEATURES

Local context and climate

The school to-be-built is located in a flat land within the city territory of Imola, at the edge of the Apennine hills. Imola borders the Municipality of Bologna, with which it shares the main climate characteristics (Table 2). For energy simulation purposes a TRY was acquired from the local Environmental Agency, while standard Bologna's

(2) This activity has being carried out since 2003 by ISO/TC59/SC17 (*Sustainability in building construction*) and, more recently, by CEN/TC350 (*Sustainability in construction works*). The first published documents are: ISO/TS21930:2005 – *Sustainability in building construction – Framework for the assessment of environmental performance of construction works – Part 1: Buildings*; ISO/DIS21931:2005 – *Sustainability in building construction – Environmental Declaration of Building Products.*
(3) A standard proposal is in course of discussion within UNI/CPE/WG10 (*Sustainability in buildings*).

hourly data for all other variables (solar radiation, air humidity, wind velocity and direction) were used.

TABLE 2
Average monthly values of the main climate variables

month	ave. temp. (°C)		daily radiation (MJ/m^2)	wind		relative humidity (%)	
	t_{min}	t_{max}		ave. vel. (m/s)	prev. dir.s	min.	max.
January	-0,7	5,9	5,2	2,9	W-N	73	92
February	1,3	9,3	7,8	2,8	W-N	63	90
March	4,5	14,0	13,6	2,9	W-S	53	87
April	7,8	18,1	17,2	2,9	S-E	54	89
May	11,8	22,9	21,2	2,9	S-W	52	87
June	15,6	26,9	23,0	2,8	S-E	48	86
July	17,5	29,8	23,3	2,9	E-S	45	86
August	17,5	29,4	19,9	2,7	E-S	47	86
September	14,6	25,5	14,9	2,7	S-W	52	89
October	10,0	19,4	10,3	2,8	W-S	64	93
November	4,8	12,4	6,1	2,9	W-NW	75	95
December	0,0	7,0	4,3	2,9	W-N	74	93

Building characteristics

The building shape is characterised by a double linear rectangular-plan structure with two non parallel wings connected by a central atrium. The longitudinal axis is placed alongside the E-W line so that the main façade of the school rooms wing is South oriented with a 15° deviation toward West. No obstacles cast shadows on the South façade during winter. The building under design is shielded by the existing Elementary School building against the winter prevailing NE wind, while is well exposed to S and SW summer winds.
The foreseen spaces and related activities are distributed on four floors: one below grade (for services and deposit) and three above grade (for the school main activities). The spaces on the floors above grade are connected vertically and horizontally through, respectively, stairs and corridors/balconies located within the central atrium. The whole South wing is occupied by classrooms and related services. The North wing has different functions at each floor: library and cafeteria at the ground floor; laboratories and conference room at the 1st floor; laboratories and offices at the 2nd floor (Figure 1).

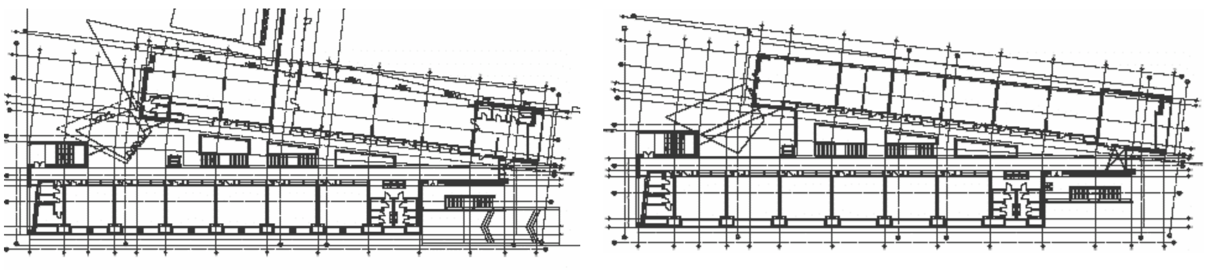

Figure 1: School building layout: plan of ground floor (left) and 2nd floor (right)

The building structure is made of reinforced concrete with pre-tensed floor slabs. The envelope is composed of dry assembled, highly insulated, and ventilated walls and roof, supporting specialised components such as water solar collectors and PV panels on roof, and air solar cavities on walls. All building products, materials and components are free of VOC and toxic emissions, particularly for indoor exposed materials. Technological performance was fully integrated to architectural quality. Figure 2 shows 3-D representations of the building from the main points of view.

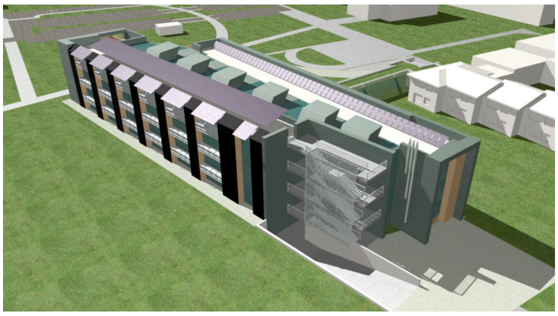

Figure 2: 3-D representations of the school building, from SE (left) and NW (right)

ENERGY SAVING CHARACTERISTICS

The following energy saving and RES-based strategies/systems were applied to the school building project, considering the connection to a district heating network, potentially available also for cooling.
For indoor climate control: high insulation of opaque (0.30 W/m^{2}K, surface averaged) and transparent (1.57 W/m^{2}K) building elements; solar control through fixed and movable screens; heat recovery on the ventilation system (VEN-R); *Solarwall®* system on the south façade; optimisation of the mechanical ventilation system; structural cooling by night natural ventilation; earth heat exchangers.
For domestic hot water: vacuum solar thermal collectors, placed on roof (North side).
For electricity production and use: 396 m^2 of solar PV panels, placed on roof (South side); energy efficient lighting appliances; daylighting-controlled dimming devices.

THERMAL ANALYSIS

A thermal annual analysis of the school building project was carried out using the simulation program TRNSYS, version 16[4], coupled with COMIS. Feustel (1990).
The building was divided in twelve thermal zones. Firstly, a simulation of the yearly thermal behaviour of each zone was carried out considering the building configuration as designed both free-floating and with the heating system. Secondly, separate simulations related to each of the energy-saving strategy/system applied as well as to reference configurations, were carried out in order to obtain the net annual thermal energy need related to each system.
The overall annual net energy need for space heating is 179500 kWh, corresponding to 37.4 kWh/m^2-floor, distributed among the thermal zones as follows: atrium, 47%;

([4]) TRNSYS Coordinator: Solar Energy Laboratory, University of Wisconsin-Madison, http://sel.me.wisc.edu/trnsys. TRNSYS Distributor: CSTB, http://www.less-inc.com.

southward classrooms and related services, 26%; northward classrooms and labs, 15%; library, 10%; cafeteria, 2%.
As output examples, Figure 3 and Figure 4 show the hourly annual profile for the southward classrooms, respectively, for indoor air temperature and airflow rate.

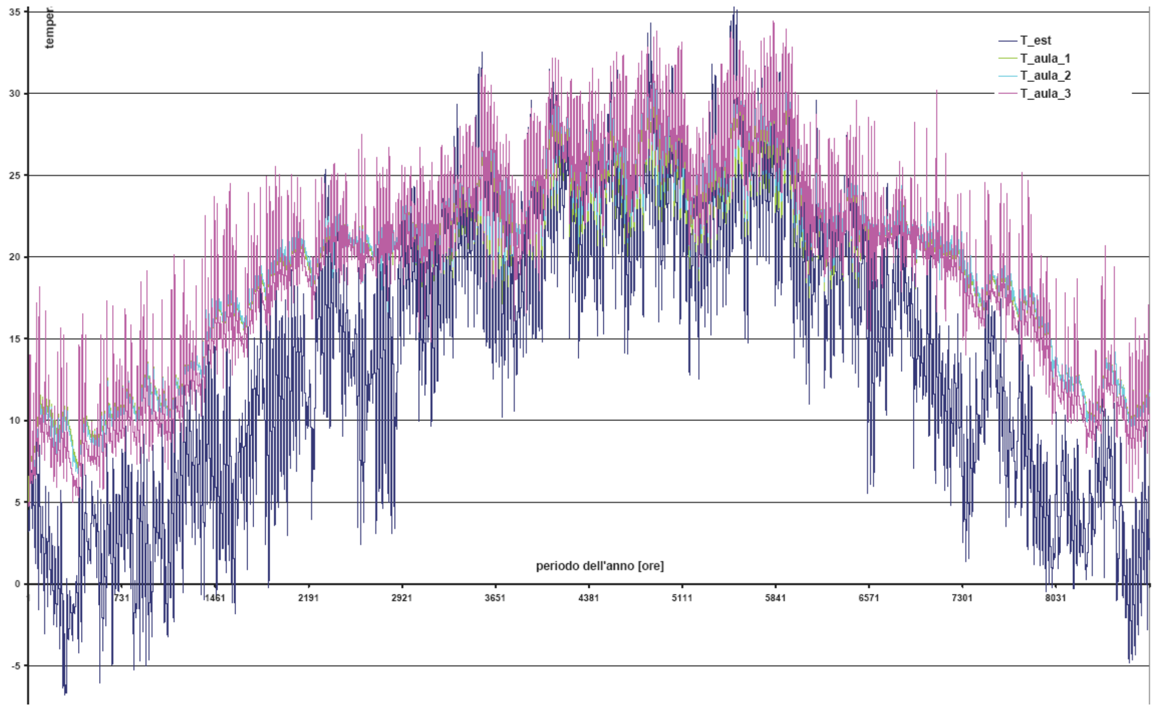

Figure 3: Ambient temperature (blue line) and indoor air temperature hourly profiles for the southward classrooms at floor 1, 2, and 3 (entire year)

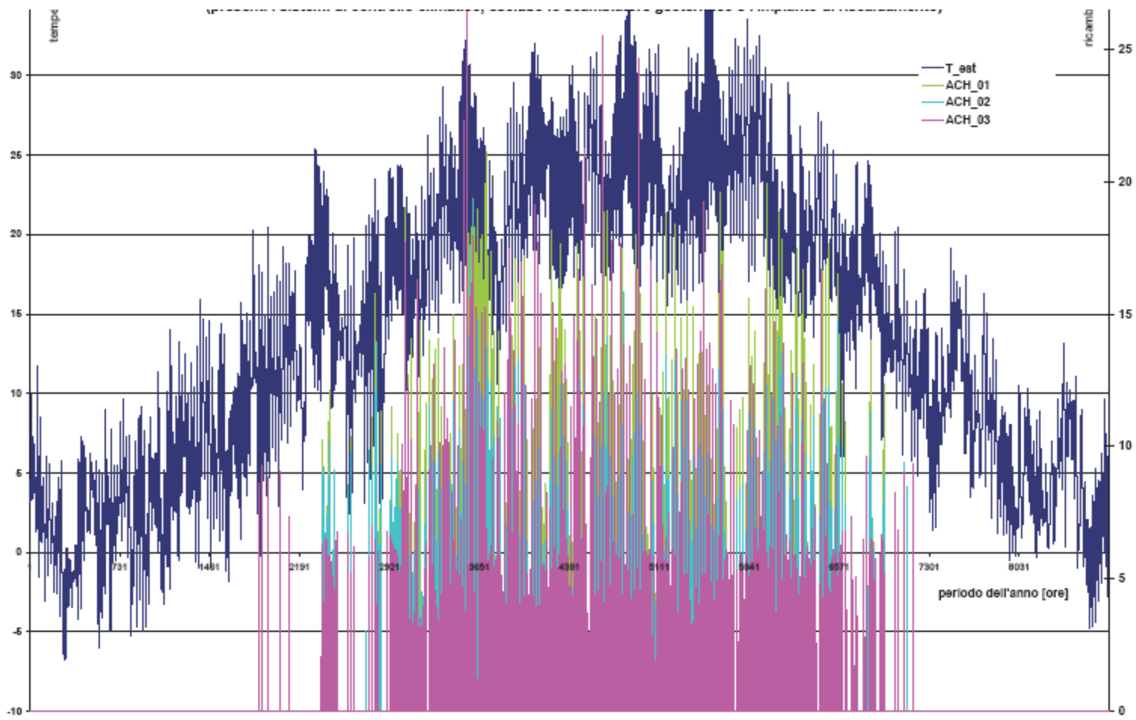

Figure 4: Ambient temperature (blue line, units on the left axis) and night ventilation airflow rate hourly profiles for (units on the right axis) the southward classrooms at floor 1, 2, and 3 (entire year)

The estimated annual net thermal energy intensity related to each of the above mentioned strategies/techniques as well as to reference configurations[5] of the school building being designed, is shown in Table 3.

TABLE 3

Annual net thermal energy intensity due to various indoor climate control strategies/system[6]

Indoor climate control strategy/system	Annual net thermal energy intensity [kWh/m²-floor]	
	heating	cooling
Reference configuration (a)	79.5	22.4
Reference configuration (b)	141.0	38.3
High insulation (opaque elements)	72.7	25.1
High insulation (transparent elements)	66.2	28.6
Time optimisation of mechanical ventilation	64.9	15.4
Fixed external shading devices	84.0	15.8
Fixed and movable external shading devices	86.8	14.0
All envelope features	67.0	20.1
Env. features + MV optim. + heat recovery	44.3	13.4
Env. features + MV optim. + Solarwall®	42.5	13.4
Env. features + MV optim. + Structural cooling	54.1	6.6
All integrated strategies/systems	**37.4**	**6.6**

STACK-DRIVEN AIRFLOW SIMULATION

2-dimensional CFD simulations were carried out to evaluate the cooling potential of natural airflow driven from outside through the southward classrooms by the top openings of the atrium. Results show a fairly high airflow rate as well as radiative and convective thermal exchanges between air and slab surfaces (both ceiling and floor) depending on the air temperature gradient and time as well as vertical distance between air inlet and outlet. Figure 5 shows an output example for a 10 °C gradient.

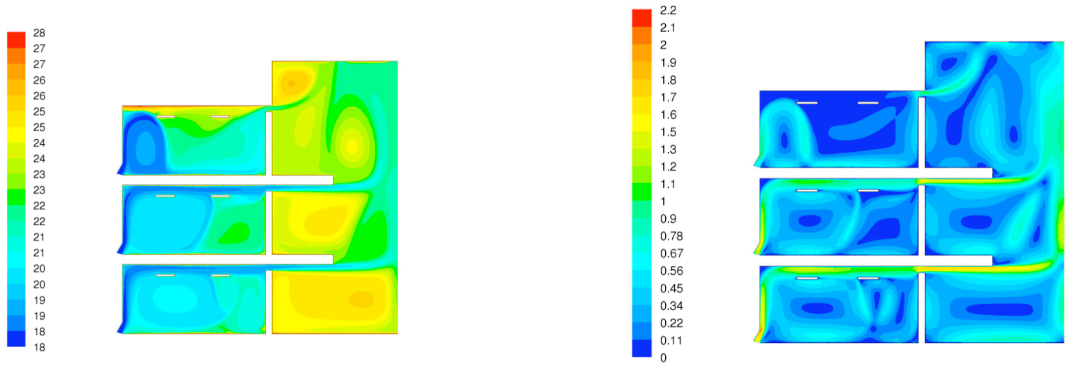

Figure 5: Example of output from the CFD simulation – airflow through classrooms and atrium; air temperature (left), wind velocity (right).

References

Grosso, M. (2005). L’efficienza energetica nella valutazione d’ecocompatibilità dei progetti edilizi. *Il Progetto Sostenibile*, **III:6**, 66-67.

Feustel, H., et al. (1990). *Fundamentals of the Multizone Air Flow Model - COMIS*, IEA-Air Infiltration and Ventilation Centre, Technical Note AIVC 29, Coventry, UK.

([5]) Two configurations with insulation as required by the national law (0.45 W/m²K for opaque elements, 2.65 W/m²K for transparent components), a conventional HVAC system, no RES-based systems, and mechanical ventilation functioning: a) 12 hours/day; b) 24 h, during the occupied period of the year (September-June).

([6]) Calculations for single systems are performed using U-values of the reference configurations, while the reduced U-values were used for the combined strategies; all simulations, except reference (b), consider 12 h/day mechanical ventilation.