Environmental sustainability in scholastic facilities: an integrated assessment of building and food

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ABSTRACT

A methodology for the integrated sustainability assessment of schools facilities is presented together with its application to a case study in Milan. The study uses quantitative indicators such as non-renewable primary energy to quantify the total amount of energy used by student related to building energy consumption for comfort conditions and to food embodied energy consumed in the school canteen (from agricultural production to the cooking stage).The result is a critical review of possible sustainability improvements of the school service. In particular heating and electricity uses and food consumption are shown in the form of non-renewable primary energy. The final part describes the main improving strategies and measures their effectiveness in terms of primary energy reduction, expressed in terms of MJ per student per year of non-renewable energy. The proposed strategies include improvement measures on building envelope and on diet changes towards low energy scenarios.

INTRODUCTION

The work presented in this paper is part of the "Bioregione" research, funded by Fondazione Cariplo (www.fondazionecariplo.it). It illustrates a summary of the current state of development of the methodology Elar (Ecodynamic Land Register) with data relating to the school service.

Elar is a methodology to support energy and food integrated plans aided by application tools. The aim is to guide the suggestion of local self-sufficiency scenarios in an area defined as local (Clementi, 2008).

Thus, in accordance with the bioregional paradigm, this methodology should be used as a tool to assess the achievement of the self-sufficiency in local areas of different entity, from the municipal scale to larger areas.

The Bioregion research aims to propose different scenarios to bring together the local demand of catering and the supply potential of the region of Lombardy considering the public facilities sector.

As the school service is one of the main actors who express the collective demand for food in the regional area, Elar has been implemented in such a way as to allow the evaluation of the environmental impacts of the school service.

These activities allow the achievement of two main aims:

1. the development of different scenarios to bring together the local demand of catering and the supply potential of the region of Lombardy considering the school sector (the main aim of the Bioregion research);

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2. the development of the database to support Elar, with useful data to integrate the school service in the development of integrated food and energy plans.

All the data collected in this phase of the investigation allow to compare the energy consumption of buildings (energy consumption for heating and electricity) with the energy consumption due to the food supply chains.

In this way it is possible to assess the whole school service and to evaluate its sustainability level. Using quantitative indicators (such as the primary energy amount) and an appropriate functional unit (such as the annual primary energy consumption per student) it is possible to verify the effectiveness of different improvement scenarios.

METHODOLOGY

The main stages of Elar are the evaluation of the local demand for energy and matter and the implementation of local self-sufficiency scenarios through the adoption of best practices (stored in a specific database). The first aim is to reduce the energy and matter demand in the school sector, the second one is to better understand how the energy and matter demand could be satisfied by the local and renewable supply.

The studies conducted in the school sector reported in this text are related to the first phase, and they aim at reducing the energy and matter levies.

The ways to reduce the consumption of energy and matter in the school sector are listed in a database that shows different studies and data taken from the literature about specific best practices potentially transferable to the case studies investigated.

The transferability of good practice are related to the awareness of similar conditions related to the case study under analysis.

Considering the energy consumption of school buildings, similarities must be verified by the following points:

1. Climatic conditions (the same/similar weather conditions)
2. Use condition (the same use of the building)
3. Technological features (similar thermo-physical properties of the envelope an systems features)
4. Geometric features (similar ratio between surface and volume and between transparent/opaque areas)

Considering food consumption, similarities must be verified by the following other points:

1. Climatic conditions (to associate information on best practices about food production in the local context)
2. The number of users
3. The type of users (age of groups, etc.)

The choice of several alternatives is entrusted to impact indicators such as the accounting for primary energy and equivalent productive land (basic condition for estimating the level of local self-sufficiency).

In this first phase, the primary energy amount is the impact indicator considered.

Up to date, the applications of Elar (Clementi, Scudo, 2013) have mainly been related to the residential sector and to the population food demand and mobility.

The research presented in this text deals with the evaluation of integrated services focusing on the school service.

Future insights will be related to other types of services, such as health services, sports and public administration in order to have a most comprehensive scenario of all the activities that have taken place in the area under analysis.

Following the general steps of Elar, the next part of the text is organized as below:

1. Information about the energy consumption of the school sector in Italy is presented;
2. The case study and its energy/matter demand during a year is shown (considering all its

energy consumption);

3. information on best practices for upgrading school buildings is shown, highlighting the possibility of reducing the energy consumption and the ability to use renewable energy (such information is stored in the Elar database of good practices)
4. some of the possibilities to reduce the demand for energy and matter relating to the food supply system are suggested;
5. in the final part of the text, an integrated assessment of the effectiveness of the strategies is shown, identifying the relative weight of the different strategies on the total non-renewable primary energy consumed per student each year.

THE ENERGY CONSUMPTION OF SCHOOL BUILDINGS IN ITALY

The overall energy consumption of all the Italian public schools (representing approximately the 85% of the total energy consumption in the schools sector) and private schools, was estimated at 990,000 Tep/year, of which 762,000 of fuel for heating and 228,000 of electricity.

Italians schools consist on 62,217 buildings and they comprise up to 8,845,213 students.

In the Italian case, considering that a Tep is equal to 11,630kWh, the fuel consumption would amount to 886,060 MWh and the primary energy consumption for electricity would be equal to 2.65164 million of MWh.

The contribution per student in Italy would amount to 1,002 kWh / student = 3,606 MJ / student and electricity consumption is equal to 299 kWh / student/year = 1,079MJ

Dividing this last value by the efficiency of the national electricity system (45,9%), it appears that the annual electricity consumption per student amounts to 137kWh/year. The total energy consumption for the school service in Italy amount to 4,685MJ/student.

THE CASE STUDY: A SCHOOL BUILDING IN MILAN

The case study is a primary school building in a district in the east side of Milan. It houses 300 students and it is occupied in the morning and in the afternoon from Monday to Friday (from 8am to 5pm)

Figure 1, 2. Aerial view of the school in Milan taken as case study (source: Google Maps) and view of the south façade.

Climatic factors

Degree days 2,404 (comfort temperature: 20°C)
Annual solar radiation incident on a horizontal surface: 1,450 kWh/ m^2

Geometrical features

Floors above ground: 3
Eaves height: 15 m
Net area: 4,362 m^2 (the total area amounts to 14.6 square meters per student)
Value of S/V of the building: 0.38

Technological features

The opaque vertical envelope is composed of two types of both full plastered brick, the first one covers 4,290m^2, the thickness is 17cm, the thermal transmittance is 1.34 W/m^{2}K; the second one constitutes the masonry spandrel and it covers 520 square meters, the thickness is 43cm, the thermal transmittance is 2.46 W/m^{2}K .

The vertical windows are composed of wooden frame with single glazing and they cover 1,341m^2, the thermal transmittance is 5.7 W m^{2}K.

The total vertical surface amounts to 6,151mq, so the transparent surface occupies the 22% of the total vertical surface. The part of the opaque envelope with higher value of transmittance amounts to 8, 5%. The thermal trasmittance of the covering amounts to 1 W/m^{2}K, of the ground slab 0.7 W/m^{2}K

Energy Consumption for heating in winter

The building annually consumes 146 kWh/m^2 of natural gas. Since the square meters per student amount to 14.6 m^2, the per capita consumption of non renewable primary energy is 2,132kWh/student, equal to 7,673MJ/student.

Electrical consumption

Breaking down the energy consumption of the building the following items emerge:

- power consumption of the heating plant: 12,500kWh (29%)
- personal computer: 7,500 kWh / year (18%)
- Copiers: 1,000kWh/year (2%)
- washing machine: 400kwh/year (1%)
- Lighting system: 21,000 kWh (50%) ..

Adding together all the components, the total energy consumption for the building is equal to 42,400kWh of electricity, equal to an amount of non renewable primary energy of 1,107MJ per student.

ENERGY UPGRADING STRATEGIES ON THE BUILDING

The assumptions relating to the possible ameliorative actions to reduce energy consumption of the building were chosen among similar cases in the database of Elar. The Pirandello primary school in Moncalieri (province of Turin) was adopted as case study, cause of similar climatic conditions and similare geometrical and technological features.

Climatic factors

Degree days 2,553 (comfort temperature 20°).
Annual solar radiation incident on a horizontal surface 1,470 kWh/m^2

Geometric factors

Floors above ground: 3
Gross surface area of 5,049 m^2
Value of S/V of the building: 0.35
Vertical dispersant surface 3,363 m^2,% of total glazed area of the vertical surface 30%.

Technological factors

Opaque vertical envelope transmittance of walls 1.45 W/m^{2}K, transparent surfaces 6.1 W/m^{2}K, covering 0.31 W/m^{2}K, ground slab 1.44 W/m^{2}K.

Energy consumption before the intervention

The real energy consumption for heating in the case of Pirandello school is 759,069 kWh, the gross volume amounts to 19,441 cubic meters, so the real consumption per cubic meter would be 39 kWh, similar to the value of the school of Milan. In this latter case the actual consumption amounts to 146kWh/mq considering the net height of each floor of 4 m, the consumption for each cubic meter would amount to 36.5kWh/m^3.

Energy upgrading strategies on the building

The actions proposed in the case of Pirandello school in Moncalieri, are extracted from the data published by Silvia Tedesco (Tedesco, 2010) and consist solely of measures to improve the performance of the building envelope. They provide insulation of the ground floor, the insulation of opaque vertical external envelop, roof insulation and replace the tansparent parts with double-glazed windows with low-emittance layer, thermal transmittance 2W/m^2K.

In the case of the vertical opaque the upgrading intervention was hypothesized to isolate the masonry from the inside with polystyrene pre-coupled panels and plasterboard, not to lose the aesthetic connotation given by the presence of the elements in the facade. The implementation of this intervention guarantees a reduction of the heat dispersions for transmission greater than 60%. The thickness of the insulation measures 5 cm and 1 cm plasterboard.

The estimated reduction in primary energy consumption result of the proposed actions would amount to 65% of total consumption, going from 53.52 kWh/m^3*year to 18.61 kWh/m^3*year (theoretical continuous operation).

In the case in Milan adopting the same types of intervention consumption for heating could be reduced by the same percentage, then passing from 146 kWh /m^2 to 51kWh/ m^2, the contribution per student would therefore decrease from the current 7,673MJ/year to 2,686MJ/year.

STRATEGIES TO REDUCE ELECTRICITY CONSUMPTION

An additional intervention to reduce energy consumption could be provided replacing the lighting systems with LED lamps instead of fluorescent lamps. By adopting this solution, the actual consumption of 21,000 kWh would be reduced to 16,800. Such a calculation was performed by estimating an efficiency of 85 lumens/watt, compared to 65 lumens/watt related to fluorescent lamps. The reduction in consumption would amount to 20%, it would affect 10% of total electricity consumption (electricity s1 in Figure 4).

Considering the orientation of the building the installation of a photovoltaic system on the roof can be an effective solution. The system could perform energy exchange with the local power grid. One square meter of PV system tilted at 15 ° and facing south, allows the production of about 150 kWh of electricity (solar values extracted from the “pvgis” solar atlas with a safety margin of 5%, www.re.jrc.ec.europa.eu/pvgis/), the production of 141 kWh of electrical energy per student would require the installation of 0, 94 square meters per student of PV polycristalline collectors with the same orientation and tilt. 282 square meters of photovoltaic panels are therefore needed on the roof. The surface of the roof slopes facing south is sufficient to accommodate such an amount of solar panels, consequently, the balance between the consumption and the production of electricity in a year will be equal to 0 (electricity s2 in Figure 3).

ENERGY FOR FOOD SUPPLY AND CONSUMPTION

After noting that the number of students in the school is 300, estimation of food demand relative to meals eaten at school was carried out as follows:

The type of food in terms of the proportion of each type compared to the total mass was derived by taking the same proportions determined from the total food purchased in the urban area of Milan by the public school canteens (Spigarolo, 2014). The main foods between those consumed each year were taken into account , particularly those whose weight consumed per year per student exceed 1 kg (Table 1).

Table 1. Amount of food consumed annually by each student in the school canteen (only quantities exceeding a kg were considered) and primary energy.

Data sources related to the primary energy content associated to each food are reported in the references in the following order (a: Mila I Canals et al., 2008; b: Assomela, 2012; c: www.lcafood.dk; d: De Cecco, 2010; e: Karakaya, 2011; f: Gonzales et al, 2011)

Foods	kg/year*stud.	Primary energy, only food production MJ/year	Primary energy for cooking MJ/year	Data sources
Frozen vegetables	6,05	121,09	33,30	a
Apples	8,00	26,80	0,00	b
Bread	10,59	105,90	0,00	c
Bananas	6,89	37,20	0,00	c
Potatoes	10,16	9,85	55,87	c
Yogurt	4,13	15,52	0,00	c
Oranges	2,62	8,77	0,00	c
Carrots	6,54	11,05	35,95	c
Pears	3,06	10,25	0,00	c
Lettuce	1,96	3,32	0,00	c
Lettuce out of season	1,96	98,21	0,00	f
Pasta	8,13	127,65	44,72	d
Zucchini	3,88	6,55	21,32	c
Eggs	2,06	18,88	11,33	c
Rice	3,24	22,03	17,82	c
Tangerines	2,82	9,44	0,00	c
Poultry meat	5,20	91,53	28,60	c
Tomato sauce	1,86	18,91	10,20	e
Beef	2,45	191,31	13,50	c
Olive oil	2,57	61,59	0,00	c
Fresh cheese	3,51	155,63	0,00	c
Tomato	1,22	3,66	0,00	f
Tomato out of season	1,22	61,07	0,00	f
Milk	3,40	12,78	0,00	c
Fennel	2,66	4,50	14,63	c

The estimate concerning the non-renewable primary energy demand for food has been carried out using data from the scientific literature covering the main part of the food chain from production in the field up to the cooking. The stage of waste management are excluded from the counting. The table in figure 3 relates the annual food consumption to the amount of non-renewable primary energy used for the food production and cooking. To estimate the contribution of energy for cooking, the same value for all food cooked was adopted (equal to 5.5 MJ / kg), as an average value between the available data on cooking of vegetables, pasta, rice and meat (Carlsson Kanyama et al, 2001).

The total non-renewable primary energy consumed annually by each student for food consumption amounts to 2,127 MJ/year.

SCENARIOS TO REDUCE THE ENERGY CONSUMPTION IN FOOD DEMAND

The diet proposed to reduce energy consumption related to food demand consists of the following strategies:

1. Replacement of frozen vegetables with seasonal vegetables.
2. Replacement of vegetables produced in greenhouses with seasonal vegetables.
3. Replacing beef with chicken meat.
4. 50% reduction in protein intake from animal foods and replace them with foods of vegetal origin characterized by the same amount of protein.

To assess the relative weight of each action on the total, various scenarios are formulated. They allow to verify the contribution of different strategies to weigh the relative reduction compared to the total.

The first concerns the elimination of frozen vegetables, replaced with seasonal vegetables. The percentage reduction compared to the total primary energy used for feeding amounts to 7.3%.

The second adds to the strategies of the previous scenario the elimination of the vegetables grown in greenhouse, replacing them with seasonal vegetables. The percentage reduction compared to the total primary energy used for feeding increases to 17.4%.

The third suggests to replace beef with chicken meat: the percentage reduction compared to the total primary energy used for feeding increases to 26.9%.

The fourth is a further improving effect of the scenario 3 and foresees the replacement of 50% of the proteins derived from animals, (poultry meat and dairy products) with proteins of vegetal origin (in this exemplary case legumes). The percentage reduction compared to the total primary energy used for feeding increases to 30.6%.

CONCLUSIONS

Performing an assessment of the aggregate possible strategies, it appears that the use of non-renewable primary energy per student may be reduced by a percentage equal to 63.7%.

In summary it is the result of a 65% reduction in fuel consumption for heating due to energy efficient refurbishment of the building, a neutral electricity budget achieved through the installation of a photovoltaic system on the roof, and a reduction of the energy used to produce the foodstuffs consumed in the school canteen at 30.6%.

As mentioned in the introduction the experimental approach adopted in this study is aimed at the creation of tools to support the achievement of self-sufficiency at the local scale, through the development of integrated food and energy plans.

The spread and development of this approach are closely related to the intention by public institutions and local communities to build more resilient regional systems, based on the use of locally available resources and less dependent on fossil fuels.

The calculation of non renewable primary energy applied to all consumption categories that characterize the service provided is therefore a first essential step in this direction. The next step has not been treated in this text and has been presented in other publications (Scudo et al., 2013), it concerns the attachment to the primary energy accounting of the extension of local land needed to produce the food and renewable energy sources, intended as potential energy supply.

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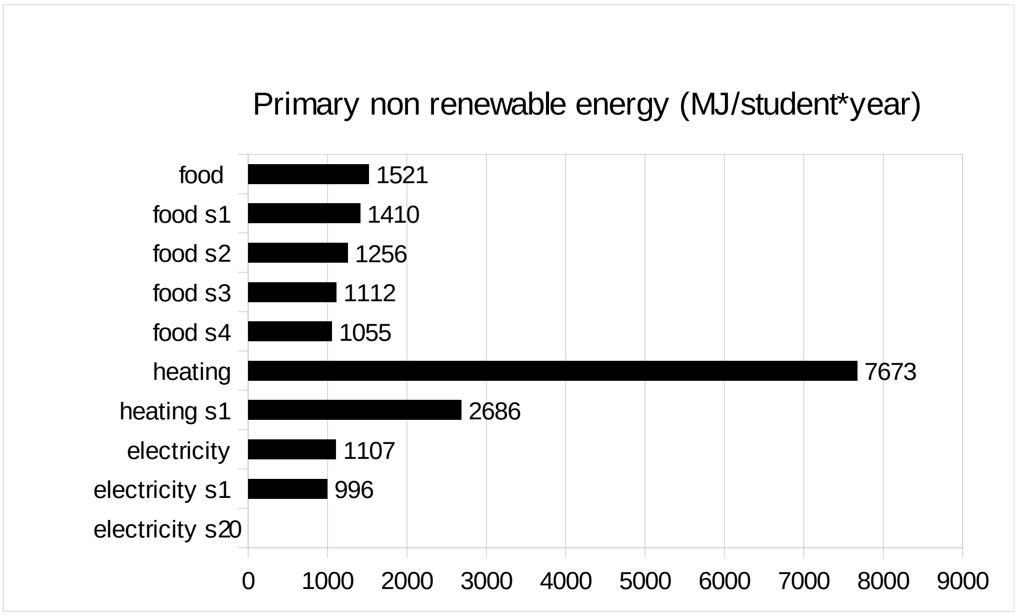

Figure 3. Comparison among items that constitute the total non-renewable primary energy per student per year. Items followed by the letter "s" refer to the improved solutions proposed in the scenarios presented in the text.

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