Feasibility study for renewable and low-energy applications in urban building sector

F. Butera, S. Ferrari, R.S. Adhikari, P. Caputo
Politecnico di Milano, Italy

ABSTRACT

Global warming and fossil energy sources depletion represent an emergency at Planet scale. As a consequence of the new regulations leading to lower energy demand in buildings for heating and cooling, new technologies such as ground source heat pump, are becoming more and more popular in many parts of Europe, sometimes coupled with PV systems. Some solar thermal applications for heating ("combi-systems") and cooling (solar assisted desiccant cooling systems) have also been developed in Europe and the interest in this area is growing. The question is: are these, and other not mentioned renewable based technologies, suitable to other geographical contexts, in particular in the Developing Countries? In this study an attempt has been made to give an answer to this question, by proposing a methodology and by assessing the issues that should be considered in a comprehensive feasibility study aiming to promote an effective low energy and renewable based approach in built environment. The approach is presented for Shanghai as a case study; however, the methodology can be applied, in general, for other kind of climates and regions.

1. INTRODUCTION

The decisive impact of fossil fuels combustion on climatic change is no longer questioned. The number and the extent of the disasters attributable to the greenhouse effect are steadily growing. The continuous increase of oil and gas price is unavoidable and irreversible, either for the progressive depletion of the reserves and for the growing demand of developing countries. Large use of coal would get worse climate change. Nuclear energy is a controversial option, also from the economic point of view; the problem of wastes is still substantially unsolved, and however also the uranium availability is limited. What could be the effect of billions of developing populations striving for a fast adjustment to the rich industrialised countries lifestyle? A clear answer comes from China, whose booming economic growth has led – in single decennium – to a doubling of the electricity consumption (Zhang et al., 2003) and to a triplication of the number of vehicles (CATRC, 2003). The construction sector grows at a rate of about 1.8 billion square metres per year (Lang, 2004) , and all these buildings require energy, thermal and electrical, to make them liveable. The consequence is that the most prudent scenarios about energy consumption forecast (China Development Forum, 2003) a doubling in 2020, with reference to 2000 (with a triplication in the building sector). And it is still a long way to go along, to reach the Japanese or European per capita consumption (presently more than 5 times higher), even if the latter are far lower than the North American ones. And yet, even with so low per capita energy consumption, China is cause of the same amount of CO_2 emissions as by USA and of the constant growth of the oil price.

The result of all this is clearly depicted in the IEA forecasts, that estimates a nearly doubling of the world energy consumption, mainly due to developing countries consumption (IEA, 2004); a doubling that, of course, will affect the CO_2 emissions in the atmosphere, with consequent impact on its temperature.

In the building sector, that in Europe accounts for more than 40% of total energy consumption, amazing results can be achieved: the present average consumption for space heating of the European existing building stock is between 160 and 220 kWh/m^2 year, on the other hand, for new buildings, it is no longer an exceptional event to design a dwelling requiring 15-30 kWh/m^2 year. To reduce energy consumption by a factor 10 is not an utopia, and the European Directive on Energy Performance of Buildings (EPBD) is a concrete step in this direction. Such savings can be obtained either with an appropriate design or renewal of the envelope and with the use of more efficient technologies.

The latter, used in buildings appropriately designed, can also give a substantial contribution to the reduction of energy consumption due to cooling, that is booming.

It is worth to notice that there is a wide range of high efficiency technologies that can be adopted at urban or district scale (e.g., CHP district heating): this is crucial for effective actions in the existing building stock.

Only after the energy demand has been severely reduced and low energy systems and plants have been considered (e.g. radiant heating and ventilation heat recovery, micro-CHP and ground source heat pumps, etc.) it is meaningful to introduce renewable energy sources. Then it will be reasonable to consider the use of solar thermal collectors not only for DHW production but also for space heating and cooling; or PV systems; or

wind energy (large and small scale); or biomass, either directly or with gasification; or biofuels, etc.
Based on these considerations, a methodology for a feasible, actual and rational promotion of renewable and low-energy applications in urban building sector is reported in the present work. It includes the climatic study, assessment of building energy consumption and feasibility of low energy building design with efficient technologies and renewable energy use. The results are presented for Shanghai as a case study.

2. THE CLIMATE OF SHANGHAI AND ITS IMPACT ON COMFORT AND BUILDING

In order to study the climate of Shanghai, the climate data of year 2001 measured by Shanghai Weather Bureau have been introduced and analyzed in this study.
The geographical location of Shanghai represents hot summer and cold winter region based on the building climate zone in China.
In fact, the 2001 data of air temperature show that the climate of Shanghai is cold (<15°C) from November to March and the lowest temperature in winter is about –5°C, hot (>25°C) from May to September and the highest temperature in summer is over 37°C.
In order to make the indoor environment comfortable, cooling must be used in summer and heating in winter. It can be predicted that with the further aggravation of greenhouse effect, the average air temperature in Shanghai will be increasing and hotter summer conditions should be taken into account in energy efficient building design.
From the relative humidity data of Shanghai (Fig.1), it has been observed that it is quite humid throughout the year, around 20% of the time the values of the relative humidity are higher than 80%, and especially in June the same value of RH represent the mean value of the month.
Therefore, in particular in summer dehumidification should be considered in Shanghai in order to make comfortable spaces, as well as the forced ventilation, as the wind speed in Shanghai is not too high (the time in which the wind speed exceeds 4 m/s is only 10% of the year and the annual mean wind speed is less than 3 m/s).
The amount of annual global solar radiation received in Shanghai (1272 kWh/m^2) is higher than most Central European locations and the technologies related to solar use in Europe can also be used in Shanghai.

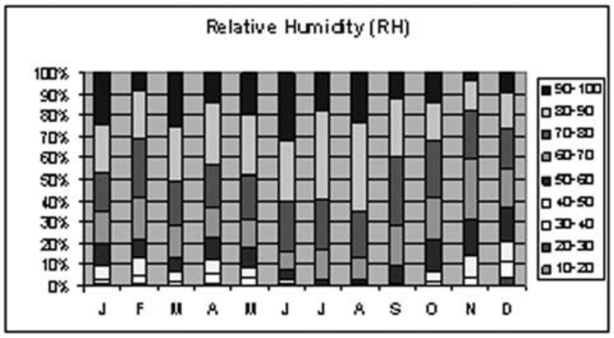

Fig. 1: Frequency distribution of relative humidity for each month

However, in summertime the values are significantly lower and the ratio of diffuse radiation to global is rather high (0.48) compared with most of world locations. This characteristic certainly affects the design and the cost effectiveness of solar assisted heating and cooling systems, with reference to those optimized for Europe.
Mean daily temperature swing, i.e. the difference of maximum and minimum monthly mean daily ambient temperatures (T_{max}–T_{min}) is rather low, especially in summer; this characteristic has a significant impact on building design.
Based on climatic conditions of Shanghai, as a first approximation an evaluation using the PMV index has also been made in order to appreciate the effect of climatic parameters in reference to the comfort conditions.

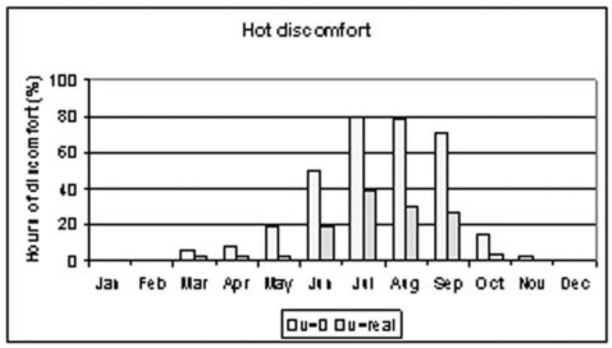

Fig. 2 Hours of hot discomfort in Shanghai climate (presence and absence of wind)

The results show that making air movement can significantly reduce the hot discomfort hours in summer (Fig.2): air ventilation in buildings could be effective in energy conservation strategies.
Referring to the main characteristics, we can identify some important topics that should be investigated deeply:
- Considering the high values of air temperature and humidity in summer, use of desiccant systems could be taken into account for reducing cooling loads;
- Evaporative cooling strategies are not suitable because of high humidity in summer;
- Considering that the diffuse solar radiation is quite high, technologies that are effective when solar radiation is

mostly direct (solar concentrators) are not appropriate;
- Adoption of shading devices for solar control should be selected carefully, in order to reduce the sky view factor in balance with natural day-lighting.
- Air movements enhancement (natural ventilation or forced with ceiling fans) could play an important role in reducing cooling demand periods
- Thermal mass has a limited importance because of the small daily temperature swing.
- Studies on appropriate building construction technologies and local, traditional architecture will be helpful for designing effective heating and cooling strategies.

3. ASSESSMENT OF PRESENT BUILDING ENERGY DEMAND AND ENERGY CONSUMPTION

There are no authorized and accepted statistical results about the current building energy consumptions in China. The energy demand for heating and cooling for a reference dwelling derive from the Chinese regulations (JGJ 134 - J 116, 2001) for energy consumption in buildings (where specific energy consumption depends on Chinese degree days range).
In fact, conventionally the heating and cooling periods (and subsequently energy demand) are identified on the basis of degree days. Based on TRY data, heating degree days (18HDD) and cooling degree days (26CDD) have been calculated for Shanghai as 1586 and 136 respectively. According to the values reported in the mentioned regulations, in view of our estimation of heating and cooling degree days, the maximum allowed electricity consumption for heating in Shanghai resulted 29 kWh/m^2 and for cooling 22 kWh/m^2. The same regulations also suggest the standard COP of 1.9 for heating and 2.3 for cooling: we derived the limit annual heating and cooling demand as 54 kWh/m^2 and 51 kWh/m^2 respectively (for the purpose of the following evaluations we rounded these values to 50 kWh/m^2, both for heating and cooling).

4. TECHNICAL AND ECONOMIC FEASIBILITY OF SOLAR ENERGY IN SHANGHAI

The potential of solar energy for domestic hot water production in a location is function of several factors, such as solar radiation and free space availability, equipment cost, back up energy (gas, electricity, etc.) cost, usage patterns, type and performance of technological systems, etc. Therefore, the evaluation of such potential must follow a preliminary study for assessing the compatibility between economics, environmental issues and space availability. The economic feasibility has been evaluated for Shanghai based on a set of calculations carried out to verify the size of the system (collector area) that correspond to the minimum value of the total annual cost (cost of solar system + cost of auxiliary energy). For the analysis, f-chart method (Duffie and Beckman, 1991) has been used to evaluate the thermal performance of solar thermal systems. All the evaluations are based on the costs prevailing in the Chinese market around year 2000 and the results may change according to updated market values. The annual cost of solar systems includes the annual instalments of the loan for the solar system, plus operation and maintenance costs. The results show (Figs. 3 & 4) that both the flat-plate and evacuated tube based systems result to be cost effective and the optimum value of collector area correspond to 3 m^2 (flat plate) and 2.5 m^2 (evacuated). In these cases back up is provided by an electric boiler.

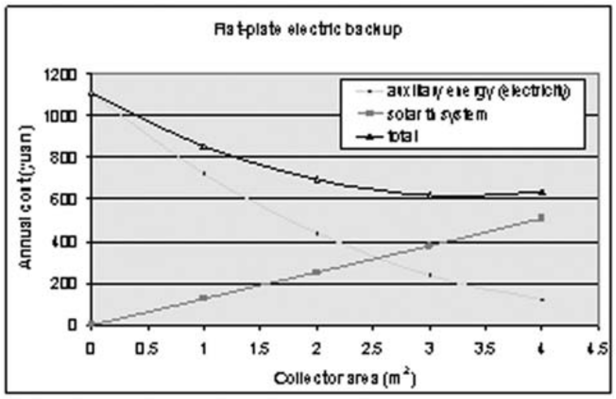

Fig. 3. Variation of total annual cost as a function of collector area (flat-plate, electric backup)

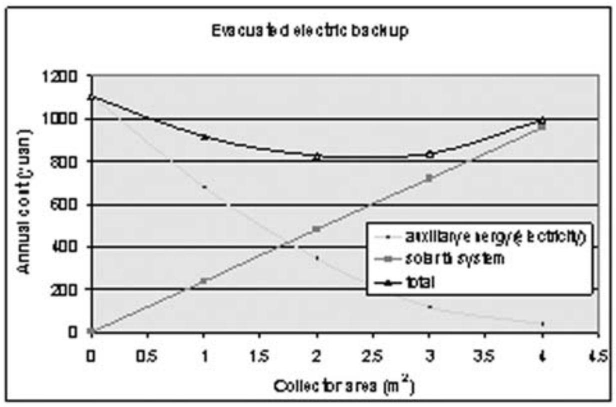

Fig. 4. Variation of total annual cost as a function of collector area (evacuated tube, electric backup)

The cost of energy plays a very critical role in the assessment of the solar energy potential. A detailed analysis, both technical and economic, is therefore required for a reasonably accurate assessment of the potential of solar thermal applications, including also space heating and cooling.

5. FEASIBILITY OF SOLAR INTEGRATED TECHNOLOGICAL SOLUTIONS IN BUILDINGS

Following the above considerations, and reminding that a sustainable building must be seen in terms of its envelope performances together with the related energy systems, a methodology has been developed for a preliminary evaluation of solar energy potential with respect to different combination of systems in buildings. The evaluations made are to be considered only qualitative, since economic data used are derived by simple rules of thumb used for the Italian market. In order to develop the methodological exercise for evaluating the feasibility of the renewable energy applications, the following heating and cooling systems were evaluated:

1. Base Case Standard: heating supplied by heat pump with COP = 1.9, cooling supplied by heat pump with COP = 2.3 and DHW supplied by electric boiler with efficiency = 95%.
2. Boiler and Chiller: heating and DHW supplied by condensing boiler with average annual efficiency = 100%, cooling supplied by compression chiller with seasonal COP = 3.
3. Ground Source Heat Pump: heating, cooling and DHW supplied by geothermal heat pump with: average annual COP = 4 when in heating mode and average annual COP = 5 when in cooling mode.
4. PV system coupled with Ground Source Heat Pump: As case 3, with electricity entirely supplied by a grid connected PV system (annual PV production = annual heat pump demand).
5. PV system coupled with high performance Air to Air Heat Pump for heating and cooling and an additional Heat Pump for DHW. Electricity is entirely supplied by a grid connected PV system (annual PV production = annual heat pump demand). COP = 3 for heating, COP = 4 for cooling.
6. Solar thermal heating and cooling system with 50% solar fraction and a COP = 0.6 for both the absorption chiller and the desiccant cooling.

The total annual costs (installment to repay the capital + operating) are estimated for each system above described. Similarly, the extra cost for improving the base dwelling were estimated, and three cases were examined, namely:

- Standard case (50 kWh/m^2 for heating and the same amount for cooling)
- Improved case (30 kWh/m^2 for heating and the same amount for cooling)
- High performance case (15 kWh/m^2 for heating and the same amount for cooling)

The last case recalls the European Passive House standard, while the Improved case recalls the present standard in one of the most energy conscious Italian Regions. Putting 100 the annual cost of a standard system presently used in Shanghai (heat pump for heating and cooling, with COP 1.9 and 2.3, respectively), and zero the extra cost for a 50 kWh/m^2 dwelling, the annual costs of the other systems were estimated and compared, according to rules of thumb applicable to the Italian market (cost of the system and cost of energy).

The result of costs analysis (Fig. 5) appears that there is always a level of envelope quality for which a minimum cost exists for each heating and cooling system. The most cost effective (i.e. the one with the lowest minimum) is the Boiler + Chiller case. The base case follows, with a slightly better envelope – very close to the GSHP system. All the solar heating and cooling systems show higher minimum costs and require better quality envelopes to be more cost effective. It should be noted, also, that very high quality envelopes lead to high total annual costs, and that all minima lie within the range of “improved” envelope.

While, if high improved envelope is considered, all the alternatives tend to collapse in the same zone.

It might appear surprising that solar thermal and PV heating and cooling systems show almost the same value as minimum in spite of the far lower cost of solar thermal collectors. This is actually explained by the fact that the GSHP is a very efficient system and that grid connected PV allows for the use of energy produced also during mid season. On the other hand, the solar thermal system is inefficient because of the mismatch between demand and production. Moreover, the COP of both absorption chiller and desiccant cooling system is very low compared with that of the heat pump.

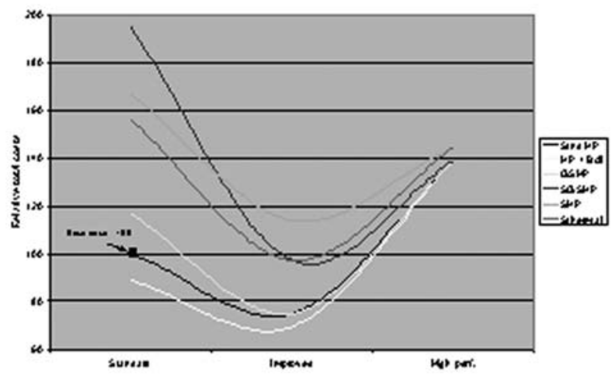

Fig. 5 Relative total annual costs comparison; Base case standard = 100

Of course, it has to be stressed that these conclusions are qualitative, and they could change after a precise cost and performance evaluation. However, the exercise points out that such a kind of analysis is necessary in order to assess the appropriate building regulations regarding either the envelope and the heating and cooling system. The conclusions, however, could change if the most likely rising costs of energy are taken into account and if the social and economical impact of CO_2 emissions is included in the calculations. In fact, each system shows a different behaviour in terms of primary energy consumption (that could change according to the characteristics of the electric generation system of the country), whereas the PV powered ones do not require any (Fig. 6).

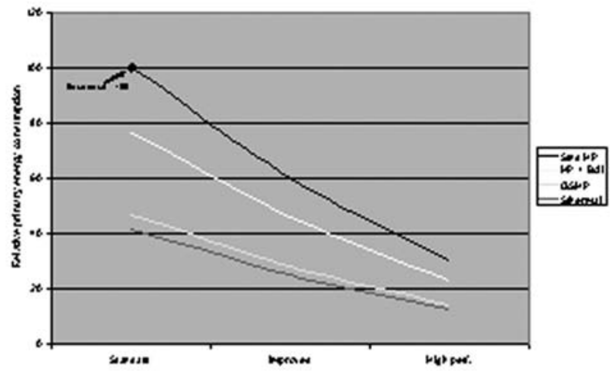

Fig. 6. Relative primary energy consumption; Base case standard = 100

In a perspective of rising energy costs this is an issue that cannot be ignored by decision makers.

6. CONCLUSIONS

A methodology has been outlined for developing guidelines for renewable and low-energy applications in urban building sector. The results are presented for Shanghai as a case study, however, the methodology can be applied, in general, for all kind of climates and regions.

The methodology has been applied mainly to solar technologies, that are not the only renewable energy technologies, neither the ones here discussed are the only low energy technologies, but most of the issues that should be treated in a complete feasibility study are raised. A similar approach can be used for exploring the potential of systems at district scale, such as district heating and cooling. These technologies may be very appealing, being possible, and economically suitable, to make use of CHP units – or tri-generation systems, using the waste heat also in summer for producing chilled water – powered not only with natural gas, but also with many kinds of biomass, either directly or via gasification. This is a very important issue, since energy consumption in the building sector is not limited to heating, cooling and hot water production: a significant and growing demand is in the electric uses (lighting, domestic appliances, etc.). Further, to that end, when new settlements are planned, another important point to be taken into account is the design of the built environment, of the skyline of the urban area and of the mix of different kind of buildings.

As conclusion, the success of the integration of low energy and renewable energies technologies in building sector in urban context depend on climate, microclimate, economic market and other important local characteristics that should be evaluated case by case, and could not be easily generalized.

ACKNOWLEDGEMENTS

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