INTEGRATION OF RENEWABLE ENERGY SYSTEMS IN URBAN BUILDINGS: FROM ENERGY CONSERVATION TO FEASIBLE ENERGY SUPPLY

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ABSTRACT

The integration of renewable energy systems, mainly active solar ones, in buildings has been an aim of intense research over the last thirty years. Solar thermal systems have become the most widespread, and certainly the most well known RES system, being a commonly accepted solution for hot water production. Within the framework of this paper, which is based on the results of the SEPEDIC-ALTENER project and the Serres project are being analysed all the aspects of RES systems integration in buildings. Aim of these projects was to determine the potential, the obstacles and the chances for sustainable development of small and medium-sized urban communities, by means of RES implementation. The analysis discussed in the paper is focused on the use of active solar systems for space heating and space cooling of residential and commercial buildings. This was done by assessing the available technologies, as well as by discussing the difficulties of sizing the collectors and the storage vessels needed to enable the integration of such systems.

KEYWORDS

Active solar systems, solar heating and cooling, urban buildings

INTRODUCTION

Active solar systems (ASS) are the most widespread, and certainly the most well known RES system. They are by now a commonly accepted solution for covering specific energy demands in the case of the final consumer. These developments were assisted, to a large extent, by national and international policies, as well by a public interest for energy, and respectively operational costs, conservation. Still, the development of the branch in the 1990's seems to move in two different directions. Some types of ASS have become well-selling products in fairly mature markets. The development does seem less impressive, when it comes to the potential for the further evolution of the market and to the question whether some of the valid support policies are sensible, or just a convenient excuse for not improving the systems' cost-benefit performance. At the same time, one cannot help but form the impression, that the development of other ASS lacks momentum, be it because the academic and the industrial community shows little, interest focusing on other RES systems, namely those producing electricity, or because the public interest has become weaker. (Tsoutsos, 2002) In that sense, and in order to approach the prevailing situation in the field of ASS, one could try to apply a SWOT analysis (Strength – Weakness – Opportunity – Threat) considering the solar systems both as independent components, as well as according to their applications. A very brief description of these four issues, as they arise from the social-economic boundary conditions could lead to the following keywords presented in Table 1. The assessment of the current situation and the future is based on these conditions.

TABLE 1
SWOT of the active solar systems' sector

Strength	Weakness	Opportunity	Threat
Mature basic technology in some systems and applications	Poor efficiency of some systems and applications	CO_2 emissions reduction agreements (Kyoto – Den Haag)	Varying political support
Acquaintance of the public with the technology	Perceived or actual high initial cost and/or technical risk of certain systems	Will/fashion to go "green" as drive to sustainable development	Low and stable prices for conventional energy
Low initial cost of certain systems	Inadequate technical support	Globalisation of technologies and markets	Externalities are frequently ignored
Attractive support schemes and measures	Superfluous support schemes and measures	Tightening of building performance standards	Traditionalism of a conservative and clustered building industry
	Lack of a branch-wide labelling and promotion campaign		Legislative and managerial barriers

PERSPECTIVES FOR THE SYSTEMS' INTEGRATION AND APPLICATIONS

Adopting the systems' integration approach, with respect to the main applications of heating and cooling one can synopsise the following arguments. There is a significant potential for development in the fields of solar space heating and cooling, which form the bulk of energy consumed in the building sector anyway. In that direction research effort leads, inevitably, to more efficient, complex and integrated systems. At the same time costs have to be reduced on basis of cost per produced unit of energy. This calls for lower cost flat plate and vacuum tube collectors with intelligent and reliable control systems. Furthermore, if one aspires to have a significant impact on the urban built environment, it is necessary to think in the direction of centralised, thermal storage systems. These presuppose a significant progress in thermal storage. The main technical points of research interest could be hence summarised as follows:

- Combined solar water and space heating systems, to achieve better economics
- Advanced solar thermal storage, to reduce the necessary installed capacities and achieve better weighted load factors
- Advanced glazing, polymers and polycarbonates to improve the cost/efficiency ratio
- Advanced controls and analysis tools to integrate solar technologies into buildings
- Building integrated and oriented solar systems and designs, including passive and active solar systems, and PV
- Centralised systems, be it on the level of a building, a building block or a residential area.
- For reasons of brevity the first two points will be discussed in this paper.

Domestic Water and Space Heating Systems

Medium-temperature solar collectors are used for space heating and operate in much the same way as indirect solar water-heating systems, but they have a larger collector array area, larger storage units, and more complex control systems. They can also be configured to provide solar water heating and typically provide 30%-70% of the residential heating—or combined heating and hot water—requirements. Active space-heating systems require more sophisticated design, installation, and maintenance techniques. Considering the development in the field of domestic water heating systems, as expressed in terms of their performance, progress has been achieved, with respect to the optimum combination of the collector's aperture area and storage volume of the vessels. If one considers the base case systems of the mid-nineties (BC) and the dream case systems (DC) described during this period, as determined by the IEA study, then one cannot fail to notice the evolution towards the features of the dream case systems as it can be seen in Table 2. (Morrison, 2001) The European trend has indeed been clearly towards smaller, more compact and faster responding systems, as it can be seen in Table 3 (Papadopoulos et al, 2001).

TABLE 2
Base and dream case systems of the 1990s : the contemporary base systems

	Canada	*USA*	*Denmark*	*Germany*	*The Netherlands*	*Switzerland*
BC-Aperture area [m^2]	5.6	2.56	4.38	6.35	2.84	5.92
BC-Storage volume [l]	273	189	295	400	115	500
BC- Volume/Area ratio [l/m^2]	48.75	73.83	67.35	62.99	40.49	84.46
DC-Aperture area [m^2]	5.16	1.49	3.0	5.08	2.75	4.48
DC-Storage volume [l]	270	138	175	300	100	430
DC- Volume/Area ratio [l/m^2]	52.33	92.62	58.33	59.06	36.36	95.98

TABLE 3
A base case system in 2001

Features	*Units*	*Facts*
Aperture area	m^2	2,4 – 4,0
Storage vessel volume per collective surface	lt/m^2	60 - 70
Optical performance coefficient (_)	-	0,68 – 0,72
Thermal losses coefficient (Fr_{ul})	W/m^2K	2,0 - 2,2
Average output	KWh/m^2	300 - 600
Cost of energy produced	€/kWh	0,04 - 0,20

The two main problems for the broader propagation of this technology, particularly for space heating, refer to the need for higher water temperatures and the gap between thermal energy supply and demand, both on a diurnal and on a seasonal base. The former problem can be dealt either with the use of vacuum tube collectors, provided their initial cost will be reduced, or with the use of low temperature heating systems, like the floor heating systems. In both cases the use of advanced and reliable controls and automation systems is necessary that will enable the efficient co-operation of conventional and solar systems, in order to avoid an overlap of the systems' operation or the phenomena like the inversion of the thermal flow in the solar system. Furthermore, a delicate balance between the building shell's thermal behaviour and the heating system's thermodynamics has to be maintained, in order to achieve in practice the expected efficiencies. In order to achieve this, a high level of scientific expertise is necessary. (Fisch et al, 1998) The study of a combined hot water – space heating system for the Mediterranean climatic conditions, with respect to the size of the building (small, medium and big) and the heating demand, as a function of the building's thermal insulation and design, lead to the results presented in Figure 1.[i] The buildings considered were typical three- to five-storied urban buildings, featuring in the Dream Case (DC) a highly efficient thermal insulation, as imposed by most contemporary European regulations. In the Base Case (BC) the insulation was average, as it was applied in the 1980's, and in the worst case there is no insulation at all, that is in the Old Buildings (OB) constructed prior the introduction of regulations. The collector's area needed to achieve a solar fraction of 40% for space heating and 95% for hot water are depicted in form of the curves, referring to the right y-axis. This, rather conservative, approach leads to a marginally acceptable economic feasibility. However, even so, the surface needed is considerable, especially in the case of bigger buildings.

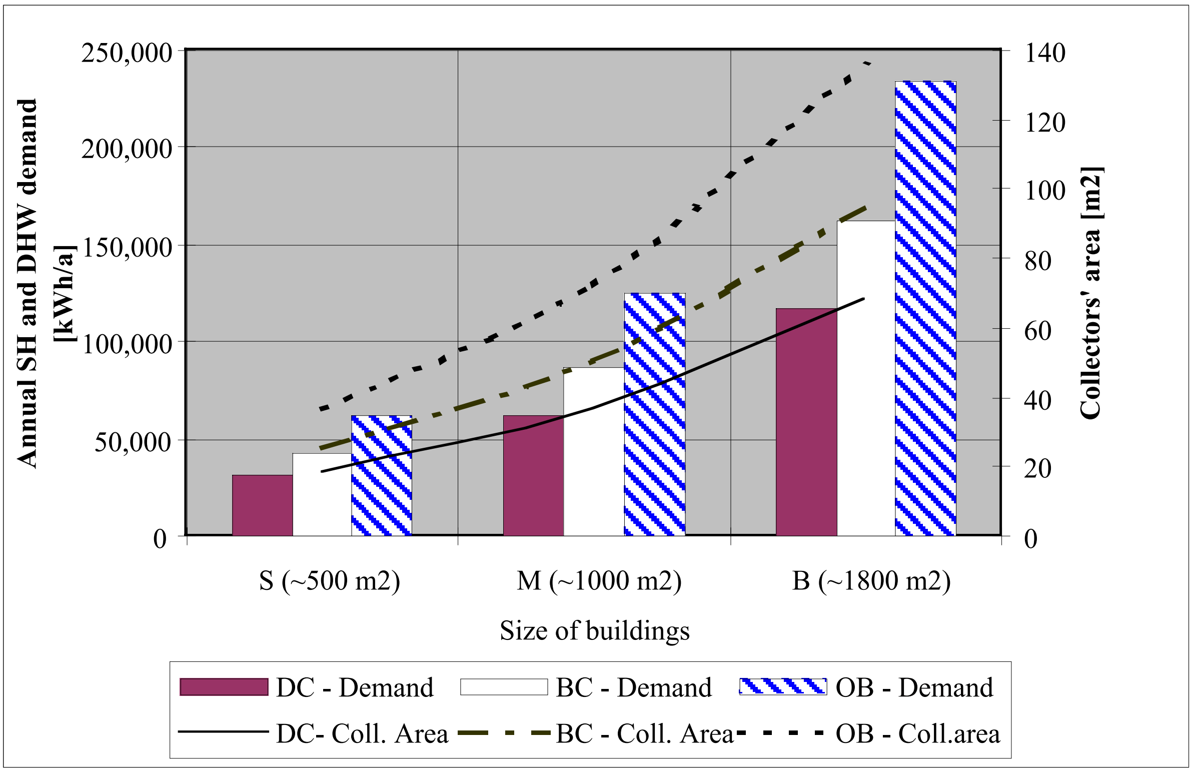

Figure 1: Space heating and hot water demand and the resulting collectors' area needed

The latter problem, of coping with the supply-demand gap, focuses on the issue of thermal storage, be it short termed or interseasonal. Thermal storage remains the decisive factor for the successful implementation of solar systems. Two thermal storage aspects are of prime importance: 1) compactness and 2) long term efficiency, aspects that apply to short termed (diurnal) as well as to seasonal storage. The current state of the art is based on storage as sensible heat in water. Water is cheap, widely available, non-toxic and has a relatively high storage density. However, even with a perfect insulation, the volume required to store solar energy is large. In the case-study of the typical buildings considered here, the storage capacities needed is depicted in Figure 2. These capacities are significant, particularly in bigger or/and older buildings. In cases of specific large consumers, like big hotels or certain public buildings, this may not pose a major problem, but there are clearly limits, in terms of space and cost, that arise in 'real-world' residential urban buildings. On the long run high density, high efficiency storage materials would make solar energy storage viable for large-scale applications in low energy houses. One technique, which may offer a considerable improvement in storage density and efficiency, is adsorption. When a water-vapour is adsorbed, energy is released and used for e.g. solar space heating. During the reversed mode (in summer) the adsorbent is regenerated (desorped) by means of solar energy. Given a storage density of approximately 140 kWh/m^3, the storage volume could hence be reduced by a factor of 3-4 with respect to the conventional water storage. Higher densities are possibly achievable on the basis of energy storage in endo/exo-thermal chemical reactions. Potential drawbacks of the thermochemical energy storage techniques studied so far are the elevated reaction temperature, the system's complexity and the presence of gaseous reaction components. Possibly the highest storage density and efficiency is achievable by omitting the thermal intermediate step and using photo-bio/electro-chemical reactions. Though photo-bio-chemistry is all around (photo-synthesis) it is not entirely understood and fundamental questions remain to be solved. However, these reactions present a low conversion efficiency (< 1 %) so far and can only be considered as cases for basic research.

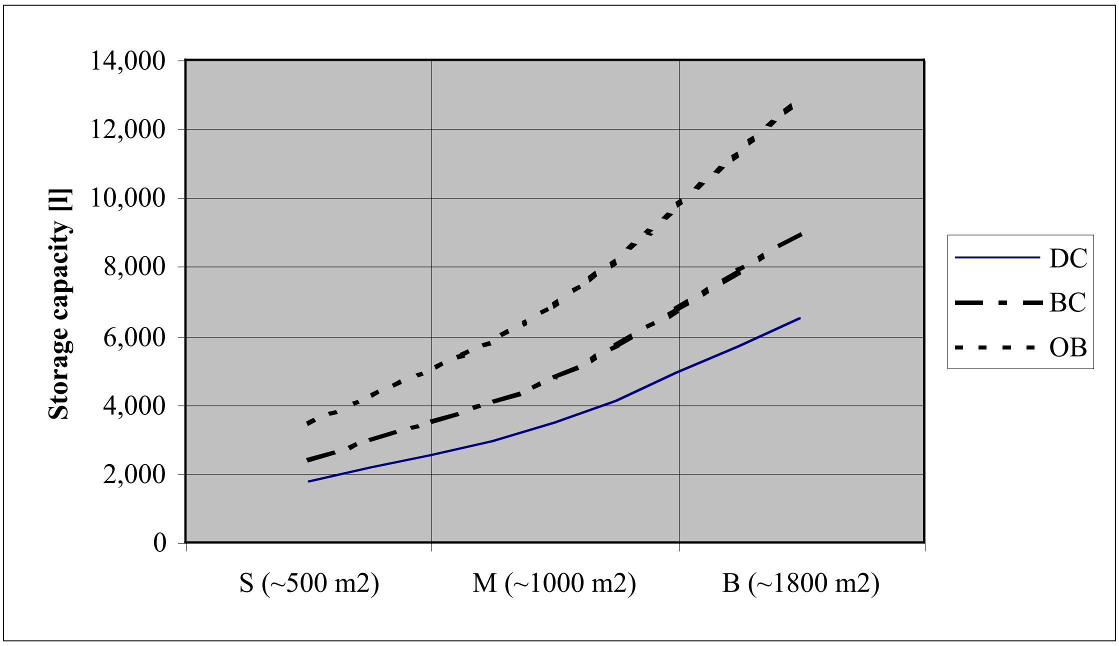

Figure 2: Storage capacities needed to achieve the design performance of the systems

The option of solar systems with air as a working medium, like the transpired air collectors, or air panels, remains in theory an attractive one, particularly in air-conditioned commercial buildings. Its application, however, presupposes suitable buildings and well-thought air-handling design, in order to avoid IAQ problems. Furthermore, the propagation of these systems depends heavily on the density of the built environment. Most European cities, with their densely built urban landscape that does not allow sufficient insolation, present a rather unfavourable field for such applications, which explains to a degree why these systems are mainly met in the USA and Canada.

Active Solar Space Cooling

Solar cooling has a promising potential for market development in the next years because of the tight correlation existing between insolation and cooling requirements. Active solar cooling is an attractive option, in order to reduce the sharply increasing peak cooling loads that burden the utilities. Still, there is no really competitive system for widespread applications that could be considered as commercially mature. Current active solar cooling systems can provide for a utilisation of collected solar heat, thereby significantly increasing the cost effectiveness and energy contribution of solar installations. These systems are sized to provide 30%-60% of the building's cooling requirements.

With respect to thermal solar systems, absorption is still the main option, though in term of efficiency and cost it is not competitive with the conventional cooling systems. Currently the main technologies, with a significant potential are flat plate collectors or vacuum tube collectors, combined with LiBr-H_2O absorption cycles, the photovoltaic / vapour compression and the photovoltaic / thermoelectric being the next best ones. Still, the annual efficiency of these systems cannot exceed 10-12%, while the net solar COP is currently in the range of 0.3–0.6. (Rannels, 2000) Additionally, the need for high temperatures (more than 100^oC) leads to highly cost types of collectors. The case of solar space cooling is certainly the most challenging one for the research in the next decade, aiming at improved efficiencies and reduced costs throw effort directed both on the on cheaper collectors providing higher temperatures and on specially designed chillers for use with low-grade heat as input. An additional option for solar cooling rises from the desiccant cooling systems. These systems drop the humidity level in the air stream by removing moisture from the air to the point that an evaporative cooler can then cool the air. Most solar desiccant cooling systems are intended for large supermarkets or warehouses, but they are also suitable for humid climates.

CONCLUSIONS

Active solar systems have grown mature over the years, at least in the field of hot water production. Still, there is a significant potential for development in the fields of solar space heating and cooling, which form the bulk of energy consumed in the building sector anyway. In that direction research effort leads, inevitably, to more efficient, complex and integrated systems. This applies particularly, if one aspires to have a significant impact on the urban built environment. In that sense it is necessary to think in the direction of centralised, thermal storing systems, whilst at the same time costs have to be reduced on basis of cost per produced unit of energy.

Currently there are favourable socio-economic boundary conditions. Developments like the large scale building renovation projects, the urbanisation, the increased thermal comfort expectations and the creation of buyer groups for solar buildings and/or solar building products, as part of an increasing environmental consciousness, are given. They present the industrial and scientific community with a unique opportunity to promote solar systems on a larger scale than done so far, not as a reaction to an energy crisis, but as a result of a thoughtful evolution.

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[i] Results drawn from

(a) ALTENER Project, Sustainable energy project for the economic development of remote and isolated island communities, Funded by CEC/DG TREN under contract no. XVII/4.1030/7/98-262, co-ordinated by AUT / LHTEE

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