# Evaluation of solar driven thermal systems for urban buildings

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ABSTRACT

The integration of solar thermal systems, 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 best-known RES system, being a commonly accepted solution for hot water production. Still, the integration of RES in the urban built environment remains limited, despite a series of ambitious demonstration projects carried out in the 1980's and 1990's and despite the significant progress monitored in the efficiency and performance of these systems. Furthermore, the impact of tightening energy conservation measures, leads to new standards for the dimensioning of energy provision installations in the field of heating, ventilation and air-conditioning. In this line of thought RES systems can be considered as energy supply utilities and not as energy conservation systems. This approach presupposes a new assessment of the boundary conditions in the market, in order to determine the opportunities presented and to evaluate the feasibility of RES based solutions under the perspectives both of the investor and of the energy user.

These aspects will be analysed within the framework of this paper, based on the results of the ATREUS project, which is funded by the European Commission Training and Mobility of Researchers Programme (CEC, TMR). 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 policies and measures needed to enable and promote the integration of such systems, not only on the level of independent buildings, but also on the level of actions affecting the communities as a whole.

## 1. INTRODUCTION

After the oil crisis in the 1970's and the increase of oil prices, society, under the fear of conventional energy shortage, turned to renewable energy sources (RES) to surrogate its energy needs. Active Solar Systems (ASS) became the most widespread and best-known type of RES system, mainly used for the production of domestic hot water (DHW). This new technology, that utilizes flat-plate collectors systems, was backed up by government sponsored research and development projects as well as by private companies that were created exclusively to manufacture, sell and install such systems. Consequently, a promising and profitable market was created, forcing, in a way, the technological development of ASS. However, by the mid-1980's the situation changed; oil prices started to fall and the public fear of a conventional energy shortage slowly faded out. The solar industry suffered badly and the majority of the newly formed companies disappeared. Those that manage to survive, improved their products, reorganised production methods and introduced quality controls in order to satisfy more exacting customer demands (ATLAS, 2004).

Since 1990's the development of this branch have moved in two different directions (Papadopoulos, 2003). On the one hand, ASS for producing DHW has been researched developed and been on the market for the past 25 years. Through these years they have been proven to be durable and reliable and therefore can be considered as a fairly mature technology with relatively low technical risk. Nevertheless, these systems are reaching a saturation point of the market, at least in some Southern European countries such as Greece, and seem to need a new technological development in order to overcome this situation and face the challenges of the future. More specifically, larger scale systems for DHW are not widespread and correspondingly the knowledge base for the design and installation of the systems needs to be improved. On the other hand, ASS for space heating and cooling seems to be stagnant, mainly due to the lack of interest from the industries and the scientists to invest in a rather expensive and unprofitable technology. At least that was the case until recently. During the last decade, a flush of solar thermal systems for heating, cooling and refrigerating technology is noticed. Even though they are technically based on the systems used for DHW, some new technologies are evolving, offering a wide range of selection according to the application.

Figure 1 compares the available solar horizontal radiation with the heating and cooling loads of a typical office building in Thessaloniki. Solar radiation refers to 10 times smaller area of the total floor area of the building.

As it can be concluded from the figure, but from Table 1 as well, the available solar radiation is adequate to cover all the heating and building loads taking into account a rational and not extremely high at all monthly efficiency of the respective solar thermal technology.

Scope of this paper is to evaluate the current

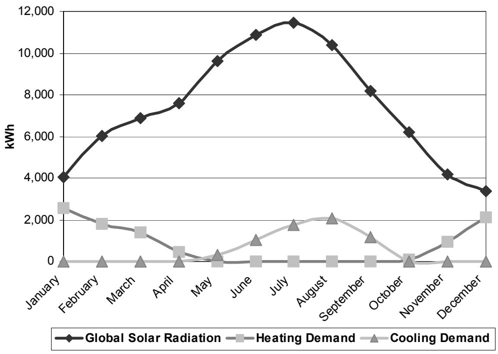


Figure 1: Comparison of available Global Solar Horizontal Radiation and Heating and Energy Demand for a typical office building in Thessaloniki.

Table 1: Monthly required efficiency of a solar thermal application to cover all of a building's heating and cooling loads in Thessaloniki.

| | Global Solar Radiation | Heating Demand | Cooling Demand | Required Efficiency |
|---|---|---|---|---|
| January | 4,037 | 2,549 | 0 | 63% |
| February | 6,022 | 1,798 | 0 | 30% |
| March | 6,887 | 1,401 | 0 | 20% |
| April | 7,611 | 465 | 0 | 6% |
| May | 9,601 | 0 | 316 | 3% |
| June | 10,860 | 0 | 1,018 | 9% |
| July | 11,471 | 0 | 1,744 | 15% |
| August | 10,396 | 0 | 2,047 | 20% |
| September | 8,165 | 0 | 1,151 | 14% |
| October | 6,198 | 110 | 0 | 2% |
| November | 4,195 | 948 | 0 | 23% |
| December | 3,387 | 2,099 | 0 | 62% |

*In kWh/m²*

situation of active solar driven thermal systems and their implementation in urban environment. In order to do so, a brief description of the available ASS technologies and the current state of the art will be presented, the necessity for turning to solar technologies will be discussed and the current ASS market situation as well as their perspective for propagation will be analyzed. Finally, the measures and politics for current and future implementation of ASS will be stated.

## 2. SOLAR THERMAL TECHNOLOGIES - STATE OF THE ART

According to the methodology widely adopted by the academic community and international organizations, such as the IEA, ASS are classified according to the produced energy form and application, the operating principle or the working medium. The main classes, when considering the applications and the produced energy forms, are presented in Figure 2 (Papadopoulos, 2003).

A brief description of the state of the art of the active solar technologies for each application (domestic hot water, space heating and cooling) as well as the current status of the various solar collector types as independent components, is presented (Papadopoulos, 2003).

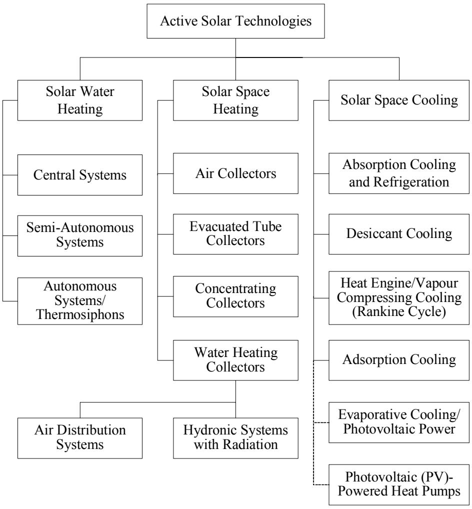


Figure 2: Classification of ASS according to the application and the produced form of energy.

## 3. WHY GO SOLAR

Nowadays, the need to turn to ASS seems more imperative than ever. Increased industrialization and urbanization in recent years induced dramatic changes to urban climate due to the heat island phenomenon, notably known for the air temperature increase in the urban areas than the rural areas, recording temperature differences up to 10°C, with direct impact on the energy consumption of buildings (Santamouris et al., 2001). Because of this, an increasing use of air-conditioning is noted, leading to an increase in electricity demand, with peaks in electricity occurring more frequently during the summer period as a result of higher environmental and urban temperatures. As an example, the summer peak load in Greece during the years 1999–2000 showed an annual increase of 16% or 1,163 MW, while for the years 1995–2000 the increase in peak load demand reached 3,500 MW. The change is also demonstrated by the daily maximum demand curves, as monitored in July 1998 and 2000, depicted in Figure 3 (Papadopoulos et al., 2003).

This trend is of particular significance, especially for insular, not interconnected electrical systems, as the additional peak demand that has to be covered leads to the necessity of installing power generation capacities, at a very low seasonal utilization factor and therefore at a high

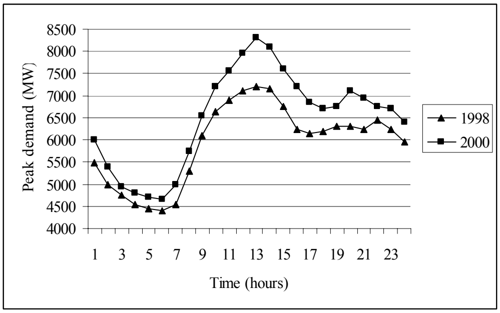


Figure 3: Evolution of daily peak load curve.

marginal cost. Even though the demand is small, it shows seasonal variations, due to periodical economic activities like tourism and agriculture. Energy loads are provided by local power plants, which can only be oil-fired and there is no possibility for connecting the local networks to the national one (Papadopoulos et al., 2004). Implementing ASS could meet all these, at a high percentage, either as autonomous systems or as a combination with conventional systems.

Furthermore, from an environmental point of view, the use of ASS results in decreased Carbon Dioxide ($CO_2$) emissions, in the elimination of ChloroFluoroCarbons (CFCs) and HydroChloroFluoroCarbons (HCFCs), the use of zero ozone depletion impact refrigerants, the decreased primary energy consumption and the decreased global warming impact, as requisitioned by European and international directives.

Last but not least, sun is an inexhaustible source of energy. The whole area of the Central and Southern Europe is a uniformly sunny area. Studies in the Aegean islands of Rhodos, Kos and Samos in Greece showed monthly solar radiation values of up to 220kWh/m$^2$, as it can be seen from the data in Figure 4 (ALTENER, 2001). These solar radiation values prove that

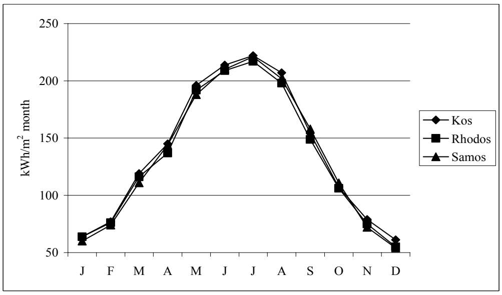


Figure 4: Monthly solar radiation in Rhodos, Kos and Samos.

Table 2: Solar thermal market in Europe.

| Country | Operation 2003 $1000m^2$ | New install. 2003 Tot Glazed $1000m^2$ | 2003/2002 Tot Glazed | Forecast 2004 Tot Glazed $1000m^2$ |
|---|---|---|---|---|
| AT | 1.922 | 167 | 9% | 200 |
| BE | 36 | 9 | 83% | 10 |
| CH | 325 | 27 | 2% | 28 |
| DE | 4.898 | 750 | 39% | 1.000 |
| DK | 300 | 19 | 46% | 20 |
| ES | 342 | 70 | 6% | 80 |
| FI | 10 | 2 | 80% | 2 |
| FR | 237 | 38 | 44% | 52.5 |
| GR | 2.779 | 161 | 6% | 180 |
| IE | 4.5 | 0.65 | 30% | 0.80 |
| IT | 399 | 50 | 11% | 55 |
| NL | 264 | 33 | 10% | 20 |
| PT | 161 | 6 | 9% | 7 |
| SE | 174 | 19 | 26% | 25 |
| UK | 150 | 22 | 26% | 26 |
| SUM | 11.997 | 1.375 | 25% | 1.706 |

the use of solar thermal systems is technically sound.

## 4. MARKET STATUS AND PROPAGATION BARRIERS

At the end of 2003, the total installed surface of solar collectors in the EU reached 12 million square meters, demonstrating a 25% increase on the previous year, as shown in Table 2.

Nevertheless, 80% of the market is still concentrated in three countries, namely Greece, Germany and Austria (ESTIF, 2004). Especially Greece is one of the most successful countries within Europe in the use of solar thermal energy, with the main solar thermal product being the domestic water heater, having the largest installed area of collectors with approximately 2.8 million $m^2$ installed (GSIA, 2003).

The application of Strength – Weakness – Opportunity - Threat (SWOT) analysis, in order to evaluate the currently prevailing situation in the field of ASS, is a good methodological approach (Papadopoulos et al., 2002; Tsoutsos, 2002). 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 3.

Table 3: SWOT analysis of the ASSs field.

| | |
|---|---|
| Strength | - Mature basic technology in some systems and applications<br>- Public's acquaintance with technology<br>- Low initial cost of certain systems<br>- Attractive support schemes and measures |
| Weakness | - Poor efficiency of some systems<br>- Perceived or actual high initial cost and/or technical risk of certain systems<br>- Inadequate technical support<br>- Superfluous support schemes and measures |
| Opportunity | - $CO_2$ emissions reduction agreements<br>- Will/fashion to go "green" as drive to sustainable development<br>- Technology's & markets' globalisation<br>- Tightening of building performance standards |
| Threat | - Varying political support<br>- Low and stable prices for conventional energy<br>- Externalities are frequently ignored<br>- Legislative and managerial barriers |

In their attempt to penetrate the market of cooling and heating systems as an alternative and feasible option and become commercially exploitable energy-production schemes, ASS have to overcome a great deal of barriers.

The main competitors of ASS are the conventional electrically driven cooling and heating systems. Since electricity is a cheap form of energy, conventional systems have a great propagation advantage over ASS. The high initial cost for installing such systems, being a sophisticated technology, is another drawback to their propagation. Moreover, the fact that ASS have, in general, pure efficiency and must be installed in combination with conventional electrical systems, serving as auxiliary systems in most cases, reduces more their integration potential.

Additionally, there is significant lack of public awareness regarding solar technology and its capabilities as well as the advantages of using such systems, together with a synchronous lack of public environmental sensitivity. Also, the lack of reliable, trained installers and maintenance technicians aggravates the public disbelief on solar systems' installation and maintenance. Besides that, there seems to be reluctance and disinterest from architectures to integrate solar systems in the designing of buildings.

Furthermore, the fact that the manufacturing sector has no important technical innovation to exhibit or no new marketing strategies to introduce for the promotion of these systems due to low budget advertisements, adds up to the overall problem of ASS's propagation. The complexity and cost of different national testing and certification procedures are barriers to European trade in solar systems. In combination, the lack, yet, of sound certification and standardization of ASS constitutes another barrier.

Last but not least, the significant lack of national support schemes in the form of subsides or appropriate sound legislation encouraging the use of environmentally friendly energy systems, do not allow ASS to take advantage of the whole range of their environmental performance when compared to conventional systems, and thus gain a part of the market.

## 5. ENERGY MEASURES AND POLICIES

Given the fact that solar systems are still, financially and technologically, not a competitive option to conventional systems, are not commercially exploitable energy-production schemes, and bearing in mind the points made in the SWOT analysis, the need for policies to develop and promote these systems in the future seems more imperative than ever. There are certain favourable socio-economic boundary conditions, such as the large scale building renovation projects, the creation of buyer groups for solar buildings and/or solar building products and the increasing environmental consciousness. If transformed into a flexible but effective framework of policies, they could contribute to an accelerated propagation of solar systems. There are three major groups of measures that can be taken towards sustainable energy policies, as presented in Figure 5, and solar systems are affected by at least two of them: technology support programmes and economic instruments (Papadopoulos, 2003; Papadopoulos et al., 2003).

Some of the points that could be part of the technological policies are industry product selection tools, development of best practices for solar buildings, guidelines for building associa-

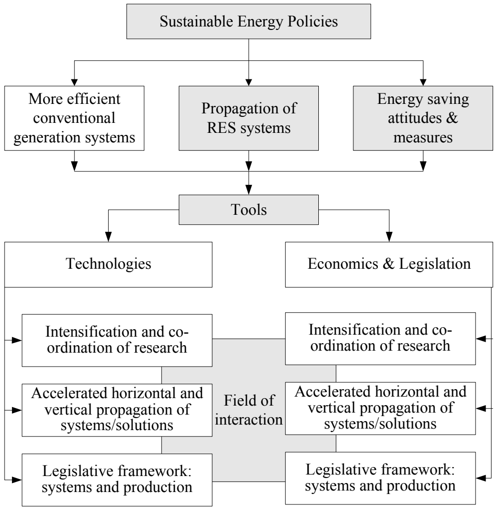

Figure 5: Tools for sustainable energy policies.

tions and decision guidelines for the purchase of solar buildings/products. These points have to form the strategic axis of action for any measures to promote solar thermal systems if it is to become successful, because, as had been proved so far, the influence of research and development projects on the promotion of systems has been rather marginal until now.

As far as economics and legislation are concerned, and beyond the conventional measures such as fiscal incentives, one could mention the following actions that could enforce a more environmentally conscious evaluation of solar systems: the quantification and internalization of environmental benefits of solar designs/technologies, the trade-off analysis of environmental issues and solar building strategies, the economic analysis and quantification of CO2 reductions from solar buildings and the adaptation of a common life-cycle analysis method to evaluate the alternatives (Rabl and Spadaro, 2001).

Moreover, a large-scale campaign has started both by the United Nations (UN) and EU with the Kyoto Protocol and the White Paper respectively, aiming mainly at the reduction of $CO_2$ emissions and at the research, development and promotion of new and renewable forms of energy, such as ASS, and also dissemination and integration.

## 6. CONCLUSIONS

Active solar technologies have grown mature over the years.

Still, there is 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.

The increasing efforts in solar research and several advances in collateral fields, indicate that both the research community and the industry are aware of the high potential of this solution. The main advantages concern the reduction of peak loads for electricity utilities, the use of zero ozone depletion impact refrigerants, the decreased primary energy consumption and the decreased global warming impact. At the same time, costs have to be reduced on the basis of cost per unit of energy produced, so that these systems can become more accessible and thus more competitive. Simultaneously there are favourable socio-economic boundary conditions, which, if transformed into a flexible but effective framework, could contribute to an accelerated propagation of active solar systems. Developments such as large-scale building renovation projects, urbanization, 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 important.

The main challenge set for the coming decade is the effective interaction between the parties involved, in order to capitalize on these conditions.

## ACKNOWLEDGMENTS

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