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ECONOMICS OF SOLAR SYSTEMS

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PREFACE

Large scale solar energy conversion for a variety of residential, agricultural and industrial uses may emerge as a significant part of future energy supply mix on a global scale. The timing for reaching such potential depends upon the management of solar technology, the economics of the various solar options, and upon the organization of their diffusion in the productive areas of their integration as a viable energy source.

The contemporary management of solar technology is often too fragmented and/or departmentalized, allowing a large variety of concepts to enter the market prior to sensible standardization and quality control measures. Retrofit installations to existing buildings are receiving primary attention, although the fully integrated energy supply systems will offer decisively better performance and economy. In fact, several preliminary studies indicate that large scale integration of solar energy could be instrumental in decoupling future energy demands from the desired economic growth trends, which ought to be the ultimate objective of future energy policies.

Solar technology, is however, still in the developmental stage, which makes projections of its competitiveness and utility in the future too speculative. The lack of actual experiences with long term reliability of solar systems, their operating and maintenance cost, and the absence of data for realistic comparison with other alternate energy systems, are among the constraining factors for pragmatic evaluation of economics.

The hereby outlined "economics of solar systems" is, therefore, only an interim effort to stimulate interest in the state-of-the-art application of solar energy for residential space and water heating, and its possible market evolution in the Countries of the European Economic Community (EEC).

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ECONOMICS OF SOLAR SYSTEMS

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INTRODUCTION OF SOLAR ENERGY POTENTIAL

Considering the long-term aspects of desirable energy policies for residential and small commercial building sectors, a viable alternative emerges calling for gradual substitution of conventional oil or gas heating by systematic integration of solar heating (and cooling, where applicable) systems. This would reduce the energy supply requirement to electric power for heat-pump operation and for emergency heating. Moreover, it will permit efficient utilization of heavy oils and of a variety of future synthetic fuels in central powerplants, where appropriate operating and maintenance measures can be applied to increase efficiency and minimize pollution. The heavy oils and synthetic fuels are generally not suitable for smaller residential heating systems.

The integration of heat-pumps with solar energy systems and with heat recovery devices compensates for the efficiency limitations of central powerplants, by delivering for each unit of electric power three to five units of thermal energy, while facilitating heat recovery and heat gain from the environment. This will significantly reduce consumption of fossil fuels and assist in reduction of pollution as well.

The systems and components needed for large-scale integration of solar heating systems and heat-pumps are still in the development stage. The reliability, lifetime and economic requirements of such systems are subject to many uncertainties, and the future prices and operating costs of competing energy systems are also merely a variety of estimates. Nevertheless, it is viewed as certain that solar energy systems will make an increasing contribution to meeting future energy requirements. Those with increasing viability are:

- -- low-temperature solar-thermal systems
- -- industrial process heat supply systems
- -- solar-thermal-electric conversion systems
- -- direct solar-electric conversion systems.

A supportable scenario for systematic market penetration of solar systems in buildings is shown in Table 1. The categories identified in this overview are based on the 1978 state-of-the-art of solar technology, projected through the year 2000, at which time other innovations may provide new options, some perhaps beyond our current imagination.

Near the end of the mid-term time period, combined thermal and photovoltaic arrays are envisioned as a possibility, together with innovative energy storage sub-systems, that would facilitate load leveling for the utilities, as well as to further reduce the energy requirements for the residential and small commercial energy consumers. Increasing use of solar systems in agriculture and industry will benefit the cost evolution of solar systems by broadening the market and stimulating large-scale production of solar-specific hardware, that will have favorable effects on cost reduction.

Table 1. Evolution of solar systems in buildings.

Time period	Solar energy system categories
1980-1985 (near-term)	Retrofits and gradually integrated solar-thermal systems for residential and commercial buildings, with conventional heating back-up, and gradual phasing in of heat-pumps.
1985-1995 (mid-term)	Optimized, integrated solar-thermal systems for residential, commercial, and industrial buildings using standardized components, heat-pumps and electric heating back-up.
1995 & beyond (long-term)	Optimized, integrated and standardized solar-thermal systems and heat-pumps, for broad spectrum of applications with increasing use of photovoltaic arrays for air circulation, ventilation, control and other supplemental functions.

METHODOLOGY FOR ECONOMIC EVALUATION OF SOLAR SYSTEMS IN BUILDINGS

Numerous attempts have been made to provide clearer visibility on the economics of solar systems. Analysis of representative cases shows that the developmental and formative phase of solar technology yielded such a large variety of concepts and early generation hardware, that accurate assessment of the economic aspects of the many solar options is impossible. However, sufficiently close estimates can be made to identify the future viability of the more mature solar options, based on increasing experience of their application, and on the increasing capital, operating and social cost of the conventional energy systems.

While it is too soon to realistically assess the cost of all solar options, since there are many promising but, as yet, unexplored concepts to be brought to the experimental and verification stage, the low temperature options for water and space heating in buildings are sufficiently developed to enter the phase of commercial use. During the 1977 Ispra Courses [1] the economic assessments for low temperature solar option in the residential sector assumed a rather gradual decrease of solar hardware cost, and continuing increases of oil prices. The recent events (1979) have shown considerably more favorable conditions for market penetration of solar systems, providing that adequate attention is given to factors influencing the economics of solar systems. Among these are:

- proper location and orientation of buildings, to maximize solar exposure.
- energy efficient floor plan; square floor plan is usually advantageous.
- optimized insulation of walls, windows, floors and roof.
- use of heat-reflecting double pane glass windows where advantageous.
- locate fewer and/or smaller windows in the north-wall to reduce heat losses.
- use appropriate outside colorings of walls and roof for given environment (i.e., light colors in hot regions).
- locate hot water tank in the south facing part of the building and close to where the hot water is needed; conversely refrigerator and freezer away from south facing walls.

Obviously, such measures are feasible mainly with newly planned buildings, and not so much for retrofit installations of solar systems in existing buildings. This brings up the fact that retrofit installations seldom approach near optimum orientation and integration requirements, and may turn marginal in economic performance, as well as in appearance. The future of solar systems is in integrated configurations, where the overall performance is a result of combining selected heating systems with other elements of the building. For example, the collectors become an integral part of the roof (or walls, or windows), providing shelter, insulation as well as heat. Current estimates indicate that such a concept for a single family house may become available for about 4600,-EUA* (1978 moneys), providing mass production and standardization requirements are met. Such houses would have only electric heating as a back-up.

The cost reduction estimates for solar specific hardware are based on the use of experience curves, applicable for large volume mass production of standardized hardware. For example, each time the production of a given component (or sub-system) is doubled, a cost reduction of 15 percent should be attainable (i.e., 85% learning curve trend). Using automotive examples**, an attainable lower limit of hardware production cost of 3,-EUA/kg (1978) and a retail cost of 4,60 EUA/kg hardware are set. This includes installation cost, which is simply an increment of the building construction cost. Further cost reductions ought to be obtainable in case of pre-fabricated buildings, in which case most of the installation work is performed at a factory, rather than on a building construction site.

In the near-term and in the early part of the mid-term time period a variety of retrofit installations will dominate the application of solar systems. Table 2 provides a method of practical evaluation of annual cost of capital investment at a typical range of interest rates. The representative annual cost factors offer a rapid comparison of economics for the various heating systems (see also SAMPLE CASES.., page 11) based on the study for the Federal Republic of Germany [2,3]. As the objective of that study was to identify the ways and means for intensified use of solar energy, the retrofit installations were viewed as essential for such an objective. Two typical retrofit solar systems for single family houses were selected:

(1) Solar water heating with 8m^2 collector surface; unit price 1900,- to 3000,-EUA; or 237,- to 375,-EUA/m^2 system price, installed. The average saving of heating oil (in FRG region) was estimated to be about 1000 liters/year.

(2) Solar space and water heating with 35m^2 collector surface; unit price 5700,- to 9500,-EUA; or 163 to 272,-EUA/m^2 system price, installed. Already, the economy of scale was visible. The average savings of heating oil (in FRG region) were estimated to be about 1538 liters/year.

These (1977) estimates for the reference systems were based on 65% annual efficiency of (oil) for space and water heating, and 20% efficiency of (oil) water heating in the summer months. The reference building was assumed well-insulated, requiring 25MWh(t) of heating per year (= 46,3 MWh(t) primary energy). Already,

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* European Units of Accounting (taken as equivalent to US$1,25).

** Based on 12 standard automobiles of 1977 production, from Citroen 2CV4 to VW1200.

Table 2. -- Evaluation of annual cost of capital investment at given interest rates.

-- Annual cost factor, $f_c = \frac{1}{(1 + i)^n} \left[\frac{(1 + i)^n - 1}{(1 + i) - 1}\right]$

Interest rates (i)	Number of years (to pay back): n = 5a	10a	15a	20a	25a	30a
0,150	3,3522	5,0188	5,8474	6,2593	6,4641	6,5660
0,125	3,5606	5,5364	6,6329	7,2414	7,5790	7,7664
0,100	3,7908	6,1446	7,6061	8,5136	9,0770	9,4269
0,075	4,0459	6,8641	8,8271	10,1945	11,1469	11,8104
0,05	4,3295	7,7217	10,3797	12,4622	14,0939	15,3725

-- Annual cost of capital investment = $\frac{\text{capital investment}}{f_c}$

EXAMPLE: Solar space and water heating system for a single family house, priced at 6000 EUA*, financed for 15 years @ 7,5% interest would cost

6000 EUA/(8,8271) = 679,72 EUA/year

If the system reduces heating oil consumption by 2000 liters/year @ 0,20 EUA/liter, its annual cost will be about 280 EUA + maintenance cost, if any.

Should the heating oil price become 0,4 EUA/liter, such a system would be earning 120 EUA/year - maintenance cost, if any.

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* 1,00 EUA taken as US$1,25.

during 1978, the market for solar systems exhibited more competitive prices, although far from being competitive with oil heating systems. The lower estimates in each case represented the future prices, while the higher ones were closer to the late 1977 averages on the FRG market. Early in 1979 increasing emphasis on heat-pump applications initiated a trend that may prove viable in the future because it could ultimately eliminate the need for conventional back-up heating systems, and gradually reduce the residential energy supply to electric power, thus reducing pollution and facilitating the consumption of heavy heating oils (saving refining energy) and future synthetic fuels (too difficult and/or too dangerous to use in households). This will also facilitate load leveling opportunities for the centralized utilities, because the heat-pumps can recharge the heat-storage (tanks) during the night hours. Such possibilities are not only enhancing the long-term economics of solar systems, but suggest considerations by energy policy makers, because an appropriate energy analysis of such concepts would indeed contribute the policy making instruments, as suggested by Malcolm Slesser [4]. Economics of solar systems fully integrated in building construction would yield reduction of the capital (and materials) intensive nature of solar energy conversion for low temperature supply to space heating. For houses having a very long survivability, the lifetime cost in terms of total energy (as in [4]) could be substantially reduced by integrated solar systems and heat-pumps, as soon as these systems are fully mature.

A rather comprehensive analysis of the economic feasibility of solar water heating was made by R. Tomkins et al., for the United Kingdom [5]. While the conventional economic appraisal in this (1976) work was not very encouraging because of the long pay-back periods for the solar systems, the energy analysis yielded favorable pay-back, showing that solar water heaters are effective conservation devices for non-renewable energy. The average 1977 price of solar water heating systems was equivalent to about 800,- EUA ($4m^2$ of collector surface) but the conventional energy cost was too low at that time to stimulate large-scale interest; this is, of course, changing. The important aspects of Tomkins' work are in the recognition of the need to validate manufacturers data and devise "credibility ratios"; over a third of the reviewed manufacturers claims proved to be clearly unattainable. The IIASA studies indicated even higher proportions of unrealistic claims, leading to very time-consuming efforts.

A detailed state-of-the-art evaluation was made in the FRG during 1976/78 time period [6] to develop an optimization aid for solar technology applications. Here too, it was established that the variety of design and pricing concepts as well as voids in essential information make a generalized optimization methodology impossible. Each application case must be evaluated individually; but even then the absence of local insolation data, their variations, and other uncertainties make true optimization impossible. Prices of flat plate collectors ranged from an equivalent of 76,-EUA to 223,-EUA for double glazed types, and from 57,- to 143,- EUA for single glazed types. Specific prices for hot water storage tanks varied from 2,12 EUA/liter to 3,73 EUA/liter for

300 liter units; from 1,77 EUA/liter to 2,48 EUA/liter for 1000 liter units; and from 1,31 EUA/liter to 2,27 EUA/liter for 3000 liter units. Controllers for solar systems ranged from 57,- EUA to 228,- EUA each, etc.

It is obvious that the solar systems cost reduction potential is limited by the materials intensive characteristics of the collectors, and the amount of energy required in their production, processing and installation. Aluminum structures are nearly ten times as energy intensive per unit weight as steel structures, which suggests a comprehensive hardware recycling program as a peripheral requirement to large-scale use of solar systems. The increasing energy prices will subsequently have significant effect on prices of solar specific hardware.

Another influential variable (next to varied insolation values) is the solar energy conversion efficiency of the collectors, which may range on an annual basis from 19% to over 40%. In the Central European climate, this represents a heating oil substitution value from about 30 liters/m^2·year to nearly 67 liters/m^2·year for space and water heating systems with about 7m^3 of hot water storage capacity. This is limited by the unused energy that is collected during the summer months but cannot be used because of the constraints of storage capacities. Larger hot water storage and higher overall system performance in more favorable insolation areas can yield appreciably higher values. This was illustrated in a recently published synthesis of solar options for Central Europe [7], and in the study of solar options for the European Economic Community [8]. The global insolation in Europe between 55°N latitude and 40°N latitude, is from about 880 to 1680 kWh(t)/m^2·year respectively. The respective sunshine durations are 1325 hours/year to 2260 hours/year and their distribution among the winter, summer and transitional months vary widely. This has, of course, decisive influence on the design performance of the solar systems and their economic viability. A model with economic, industrial and social indicators shows that nearly two million new dwellings are constructed in the countries of the EEC per year. If 12% of these dwellings* could contain integrated solar systems per year the annual heating oil savings could reach over 9 million barrels the first year and their multiple thereafter. The capital expenditure for such effort would probably exceed initially 1,40(10^9) EUA/year and stabilize near 1,10(10^9) EUA/year (1978 moneys) in several years. The full economic, industrial and societal impact of such change would not be excessive.

To illustrate further the economic scale of the transition from a typical conventional (1978) building to one with a fully integrated solar system (after 1985) and heat-pump, Table 3 provides a comparison of customary and attainable values.

Location, climatic conditions, house design, life style of occupants, etc., cause unpredictable variations of such estimates. The comparison does, however, illustrate the economic values to

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* Percentage of dwellings considered suitable for integration of solar systems.

Table 3. Comparison of various versions of a single family house.

Design	Energy consumption/year: kWh(t)/a	oil, liters/a	fuel cost EUA*/a
Conventional 120 m^2 (1978)	48800	7500	1500
Well-insulated + SES** 120 m^2 (1980)	25000	3850	700
KFA-IIASA reference + SES** 120 m^2 (1977)	10000	1430	285
Phillips experimental + SES** 116 m^2 (1976)	8300	1186	237

* based on 0,20 EUA/liter of heating oil.
** solar energy system.

the house owner, as well as those to the state in terms of contributing to the improvement in the balance of payments.

Eventually, perhaps in a few years, the use of solar systems in commercial, agricultural and industrial enterprises will reach the scale potential of the residential uses. In fact, these sectors could be considered economically more interested to use innovative energy concepts as the cost of the conventional ones rise. Regretfully, the uncertainties and the variety of possible uses of solar options are even greater here than in the residential sector. The more distinct need for higher temperatures stipulates the use of more complex hardware. Yet it ought to be realized that in such cases as production of process heat, the solar system need not necessarily attain the level of process heat required; significant savings are attainable by preheating as well. It is, for example, economically significant if a plant requiring hot water at 90°C has to use fossil fuels to heat it up from a 10°C supply line, or from solar preheated water at say 40°C or higher. The specific determination must be formulated by

- -- energy savings potential
- -- operation and maintenance cost
- -- amortization time of solar system

-- equipment up-dating priorities
-- logistics considerations
-- other applicable trade-offs.

A variety of focusing and tracking collector designs produces working fluid temperatures from 100°C to over 1000°C at near-term prices from 50,- EUA/m^2 to 400,- EUA/m^2, and future system prices from 60,- EUA/m^2 (system) to over 100,- EUA/m^2 (system). Similar uncertainties prevail as in the low temperature systems spectrum, but the energy storage requires often larger capacities at acceptable cost. Typical examples are air-conditioning systems, irrigation systems and process steam generation. Depending upon the available insolation values, a 50 kW(e) irrigation unit may require 400 to nearly 1000 m^2* of parabolic dish collectors with single-axis tracking of the sun. Current cost of such a system averages 173,- EUA/m^2, and if enough are built the cost could drop to about 60,- EUA/m^2 (system), or about 500,- EUA/kW(e). Best cost levels presently are closer to 1500,- EUA/kW(e).

Economic evaluation of solar systems would be incomplete without photovoltaic systems. Their current availability is primarily in two versions:

(1) Arrays of silicon cells (~60 W_e/m^2) for about 11200,- EUA/kW(e) to 20000,- EUA/kW(e).

(2) Arrays of cadmium sulfide + copper sulfide cells (~16 W_e/m^2) for about 16000,- EUA/kW(e) to 40000,- EUA/kW(e).

The performance estimates are subject to insolation values, of course. Cost reductions in the future should yield silicon cell panels for about 1000,- EUA/kW(e), and the cadmium sulfide versions for about 500,- EUA/kW(e). Continuing research and development is aimed at

-- new material deposition processes and junction manufacturing techniques,

-- new array fabrication and encapsulation methods,

-- new light/heat to electricity conversion concepts.

The encapsulation processes are economically as significant as the manufacturing of cells. The principal approaches are

-- aluminum-framed acrylic and weatherproof vinyl,
-- silicone rubber,
-- silicone rubber + thermal shock resistant glass,
-- strengthened glass in front + epoxy coated-metal in the back.

Cost reduction in any of these areas would also contribute to overall economic chances of the photovoltaic systems.

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* The large area would be required in Central European location, where the economic viability would be marginal at best.

Table 4. Comparison of heating cost estimates for single family houses in Central Europe.

House type	Average global insolation 1100kWh(t)/$m^2 \cdot a$					Average global insolation 1100kWh(t)/$m^2 \cdot a$				
Heating parameters	Terraced family house ~ 12.5 kW(t)					Free standing family house ~ 18 kW(t)				
	1	2	3	4	5	6	7	8	9	10
1 Type of heating*	Oil	Oil + SES RETRO	El. + SES INTEGR	El.	D.H.	Oil	Oil + SES RETRO	El. + SES INTEGR	El.	D.H.
2 Heated area, m^2	100	100	100	100	100	120	120	120	120	120
3 Spec. heat demand ~kWh(t)/ $m^2 \cdot a$	210	210	100	210	210	250	250	140	250	250
4 Cost of heating system, ~EUA	3048	8760	4600	3430	2096	4570	11920	6600	5142	3048
5 Annual cost of heating, ~EUA/a	812	1352	670	902	701	1222	1862	960	1360	1056
6 Total annual spec. cost of heating, ~EUA/$m^2 \cdot a$	8,1	13,5	6,7	9,0	7,0	10,2	15,5	8,0	11,3	8,8

Notes: *El. = electric heating;
SES RETRO = <u>retrofitted</u> solar system with oil heating back-up;
SES INTEG = <u>integrated</u> solar system;
D.H. = district heating.
All 1700 hours/a, 20a life cycle and 10% interest.

3 8 The integrated solar system (EL + SES INTEGR) includes optimum insulation, heat recovery from waste water and exhaust air and electrically driven heat-pump. Electric heating is the back-up for emergencies. Passive solar system included.

EUA = European Units of Accounting (taken as equivalent to US$1,25).

A broad spectrum of economic and commercial assessment of all these solar options was published by ISES in London [9]. The findings are consistent with all the other synthesized sources: "The uncertainties are too numerous to delineate reliable methodology for economic evaluation of solar systems".

SAMPLE CASES FOR CONTEMPORARY AND NEAR FUTURE BUILDINGS

Comparison of heating cost estimates for a terraced single-family house and a free-standing house with a variety of heating systems, shown in Table 4, illustrates the economics of retrofit solar systems, and future integrated solar systems, including the use of passive solar systems in the latter.

In this comparison, the heating oil price is 0,20 EUA/liter. The estimated annual cost of heating includes fuel cost, amortization payments and maintenance. The retrofit solar system type is assumed to save 50% of heating oil, and the integrated solar system is using electricity for heat-pump and for emergency stand-by heating (about 20% of heat demand estimate).

The integration of passive solar heating is a prerequisite for the overall integrated solar system ("SES INTEGR"). This offers a new challenge to architects because it also facilitates thermal storage (i.e., 45 cm thick thermal storage wall) in a concrete monolith, and/or in water filled pillars (~3,20 EUA/kWh$_t$ for water). Figure 1 shows a schematic of the entire concept. Movable insulation panels for shielding the large window area in front of the storage wall would further improve the efficiency of the system. Even phase change materials could be used, storing the heat input during their melting phase, and releasing it during the solidifying phase.

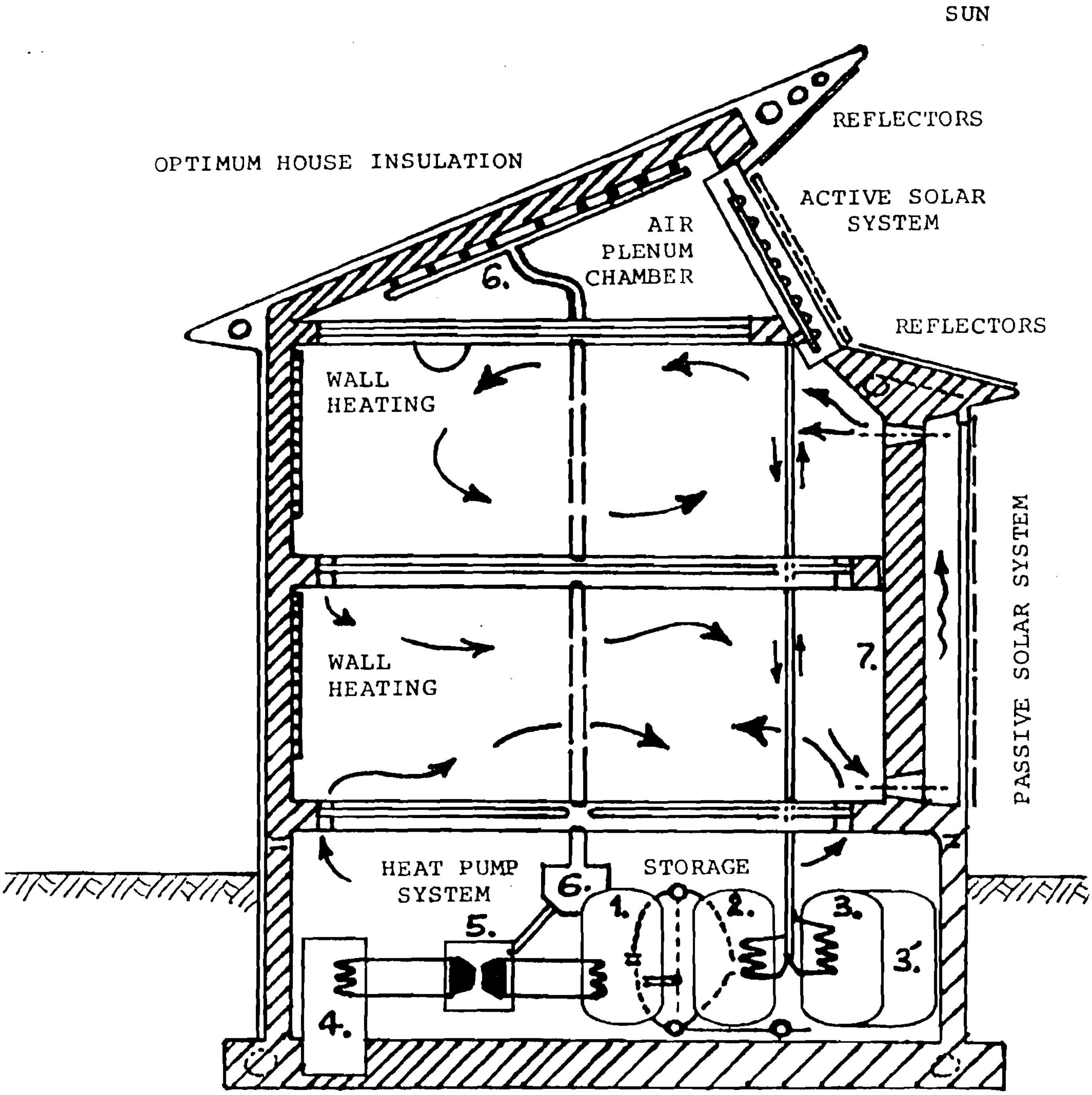
Altogether five concepts for a passive solar system may be considered when appropriate exposure to the sun is available:

(1) Large, south facing window(s) in a well insulated building, where the interior walls and floors act as thermal storage media. In favorable cases, this can reduce the conventional heating fuel demand by 50%.

(2) Thermal storage wall (or liquid filled pillars) behind a large, south-facing window, separating the incoming heat from the living/work spaces, and providing appropriate venting to induce thermally driven air circulation.

(3) Integrated atrium (green house) on the south side of the building, separated from the living/work space by a thermal storage wall, equipped by venting openings.

(4) Natural convective loop with working fluid (liquid or or gas) heated in collectors located below the space to be heated. The sun-heated working fluid rises and stores the heat within the building.



1. High temperature water storage (up to 70°C)
2. Moderate temperature water storage (up to 50°C)
3. Low temperature water storage (30 to 40°C)
4. Waste water holding tank (heat recovery)
5. Heat pump system
6. Air heat recovery heat exchanger in air plenum chamber
7. Thermal storage wall

Figure 1. Elements of an integrated solar system in buildings.

(5) Roof pond with liquid (optionally in plastic bags) exposed to the sun during the day and covered by panels during the night, functions as thermal load leveling.

Combination of some of these concepts provides opportunities for novel architectural designs, dimensioned to the given climatic conditions. The heat storing structures protect the building interior from elevated temperatures during the sunshine and transmit the stored heat to the interior of the building at night. Up to 80% of the annual heating requirements can be conserved in favorable locations.

In addition, heat recovery from the air exhaust, as well as from the waste water provide heat source for the heat-pumps and supplemental energy for the storage tanks.

Combination of the energy conserving features in the integrated solar system would yield favorable results for large buildings as well. This was recently outlined for a 70 units "IIASA Hotel" proposed in a region with global insolation averaging 1066 kWh(t)/m^2·a and a convenient access to a relatively shallow water table. The following interim specifications emerged from the initial assessment:

Building type: five storey structure with 70 room-units, administrative and recreational rooms and space for conventional services.

Total area to be heated: about 2600 m^2

Total space to be ventilated: about 7800 m^3

Area of solar collectors: about 315 m^2

Specific heating requirements: about 80 kWh(t)/m^2·a

Maximum water heating requirements: 100 kWh(t)/d

Heat-pumps capacity: 5 × 5 kW (perf. index 3,5-4.0)

Main hot water storage: about 500 m^3

Stand-by hot water storage: about 5 m^3

Waste water holding tank: about 3 m^3

Air plenum chamber: about 150 m^3

Assuming hotel occupancy of 30 % min., the heat recovery from water and from air will be a major contribution to meeting the heating demand of the building (estimated near 200 MWh$_t$/year), equivalent to 30770 liters of heating oil/year. The estimate of the integrated solar system's cost is 88200 EUA, and the subsequent annual savings would be about 18470 liter of heating oil equivalent = 3694 EUA/year. Amortization of the investment is (88200/10,1945) = 8652 EUA/year (20 a @ 7,5%), which together with the cost of electric power is (8652 + 2460) = 11112 EUA/year (as compared with 2648 + 6154 = 8802 EUA/a for the conventional oil heating). Such comparison is, however, not correct because it deals with prototype system cost vs. conventional system cost. Mass produced components for the integrated solar system would be priced near

42000 EUA, or 4120 EUA/a, which yields an estimate of (4120 + 2460) = 6580 EUA/a, that would be competitive.

A variety of solar system installations in commercial, industrial and agricultural facilities can be economically attractive, once the mass production of standardized components and solar-specific sub-systems is in progress. Each case will have to be evaluated individually to avoid building marginal, or even unprofitable systems.

MARKETING POTENTIAL ASSESSMENT

An attempt to conduct realistic evaluation of the market for solar systems is premature at this time (April 1979), because of the numerous uncertainties outlined in this synthesis. At the time of writing, there are neither institutional nor industrial commitments to pursue logical measures for the attainment of a significant cost reduction of solar energy conversion hardware. Only sensible standardization (to assure availability of fitting spares) and mass production of the hardware can lead to cost reduction rates exceeding inflation rates and coping with the increasing cost of energy, which is after all one of the key elements in hardware cost. Once the needed measures are instituted the market potential in the EEC countries alone will build up to the 1,10(10^9) EUA/year noted earlier (page 7). The 240000 systems/year for the residential sector alone in the EEC countries would then be a reasonable goal within the industrial and economic framework. Considering spares and next phase start-up, about 10 million square meters of flat plate collectors per year would be needed for this option. If ten large industrial facilities are assigned such a task, this production capacity could be reached (with proper priorities) in about six to seven years (allowing 1 to 2 years for tooling up), during which time the management would have to pursue the "85% learning curve" to meet the cost reduction goals as well. Each of the facilities would have to be automated for this task, involving only about 50 men crew in the manufacturing process.

Table 5 shows a possible distribution of the market in the EEC countries, based on the 1976/78 studies of the residential and other sectors [2,8]. Evaluation of other than residential sectors was not possible within the scope (and resources) of this synthesis. It is, of course, certain that the interest of commercial and industrial, as well as agricultural sectors will grow in relation to the increases of energy cost. It is however, the responsibility of solar business enterprises to provide objective guidelines for the application of the various solar options and delineate the trade-offs with alternate approaches to strengthen the case for solar systems in truly useful configurations.

Table 5. Installation rates of solar systems in EEC countries--basic scenario.

Countries N-S arrangement:	Sustaining average of building construction rates; Units/year:	Installation of solar systems in residential units; Units/year:
Denmark	49000	6000
United Kingdom	300000	37000
Ireland	23000	3000
F.R.G.	630000	80000
Netherlands	149000	18000
Belgium	59000	7000
Luxembourg	2500	1000
France	520000	63000
Italy	200000	25000

CONCLUSIONS AND RECOMMENDATIONS

A synthesis of the referenced 1976/78 studies shows that formulation of a realistic methodology for economic evaluation of solar systems is not feasible as yet, because of numerous uncertainties, design variables and pricing techniques that cannot be adequately categorized. Solar technology is in the developmental stage. Its successful, large scale use stipulates standardization of dimensional criteria and mass production of the solar-specific components. This should lead to significant cost reduction that is among the key requirements for accelerating utilization of solar energy.

It may take 20 to 50 years for effective diffusion of solar systems, depending upon the trends in petroleum pricing and upon the evolution of other alternate energy systems. An "end product" oriented technology assessment of solar options is needed for commercial, industrial and agricultural uses of solar systems, so that their economic viability is clearly established. Until that time, care must be exercised to prevent premature commitments in too speculative areas. The time for full scale use of solar options will undoubtedly arrive--being prepared for that time must be viewed as the key issue.

Retrofit installations of solar systems for space and water heating are often marginal in their economic performance. Intensified emphasis should be aimed at integrated solar systems and their optimization with other energy conserving methods for each category of specific applications. Combination of passive, active and ultimately photovoltaic systems, together with optimum insulation, heat-pumps and heat recovery systems offer performance advantages that may facilitate load leveling management and new energy distribution logistic.

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