IEA SOLAR HEATING AND COOLING (SHC) PROGRAMME, TASK 20:
SOLAR ENERGY IN BUILDING RENOVATION

Solar Collectors in Building Renovation

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INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

Contents

International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme, Task 20: Solar Energy in Building Renovation

If the use of solar energy is to mean that significantly less fossil fuel will be consumed, solar systems must be readily adaptable to existing buildings as well as new buildings. Under IEA SHC Programme Task 20: 'Solar Energy in Building Renovation', a number of the most promising solar concepts and systems for building renovation have been explored.

The first activity of Task 20 was the analysis of the performance of existing solar renovation projects that appear to be based on broadly applicable design concepts. Then on the basis of the information gained from these case studies, the participants investigated improved and advanced solar renovation system concepts with high potential for both energy savings and replication. Strategies for incorporating these concepts into the renovation process were developed for a number of specific projects.

The countries participating in Task 20 are: Belgium, Denmark, Germany, The Netherlands, Sweden, Switzerland and the USA.

Acknowledgements

The support of BFR (The Swedish Council for Building Research), which has financed the work related to this brochure, is gratefully acknowledged. My thanks are also due to all national experts within IEA SHC Programme Task 20, for valuable comments and suggestions, Kjell Jonasson and Hans Grönlund, EFEM Architects, for valuable help concerning architectural aspects and illustrations, and my colleagues in the Department of Building Services Engineering, for their valuable help in preparing the brochure.

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September 1997

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Illustrations: Hans Grönlund, EFEM Archtects

Design and production: James & James (Science Publishers) Ltd, London, UK

Introduction

The use of solar collectors integrated in the building envelope is one of the most interesting solar energy applications in connection with the renovation of *multifamily buildings*.

One of the most obvious criteria related to application of solar energy for residential building renovation is the need to repair and/or improve the building envelope from a thermal, a durability or an architectural point of view.

Building renovation may also include renovation of the heating and ventilation (HV), as well as domestic hot water (DHW) systems, which gives further opportunities for solar energy applications to be considered.

The solar renovation of a building comprises in some cases a combination of the above-mentioned activities, for example when the building envelope becomes a part of the heating or the ventilation system.

Roof constructions most suitable for solar renovation concepts using solar collectors are flat roofs either that need to be rebuilt as sloping roofs or that have roofing material that needs to be replaced

ROOF-INTEGRATED SOLAR COLLECTORS

The roof can be renovated using roof-integrated collectors, where the collector works both as a new roof cover and as a solar collector.

Facades most suitable for solar renovation concepts using solar collectors are facades where the cladding has to be replaced

A part of the facade can be renovated using facade-integrated collectors, where the collector works both as a new cladding and as a solar collector.

FACADE-INTEGRATED SOLAR COLLECTORS AND GLAZED BALCONIES

A common solar energy application in connection with replacement or improvement of the HV and DHW systems is to apply a water-based solar collector system with the main purpose of preheating DHW.

Another solar energy application is to apply an air-based solar collector system with the main purpose of heating occupied spaces, either directly or indirectly via a double envelope. In both cases the solar collectors are typically located on the roof or on the facade.

ROOF-INTEGRATED SOLAR COLLECTORS AND DOUBLE ENVELOPE (AIR GAP)

Systems

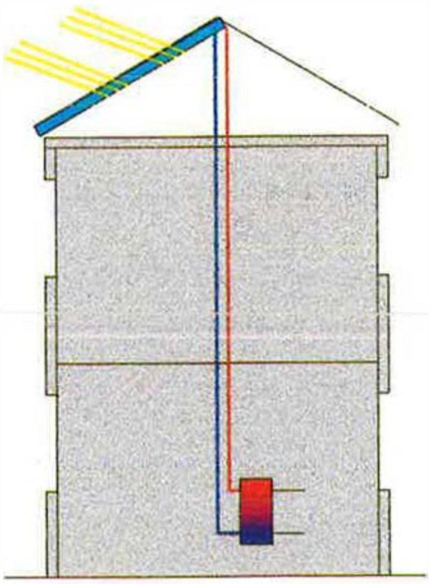
Introduction

Solar collectors are installed with the main purpose of preheating domestic hot water (DHW) and/or for space heating (preheating ventilation air or occupied spaces). The collectors are normally integrated in the roof or in a south-facing facade. Solar collectors may also be applied in order to improve the building envelope, e.g. when a flat roof is rebuilt to an inclined one using roof elements with integrated solar collectors.

There are two basic concepts regarding the system design: water-based collector systems, primarily designed for preheating DHW, and air-based collector systems, primarily designed for preheating ventilation air. Both types of collector systems may also be used for space heating.

Water-based collector systems

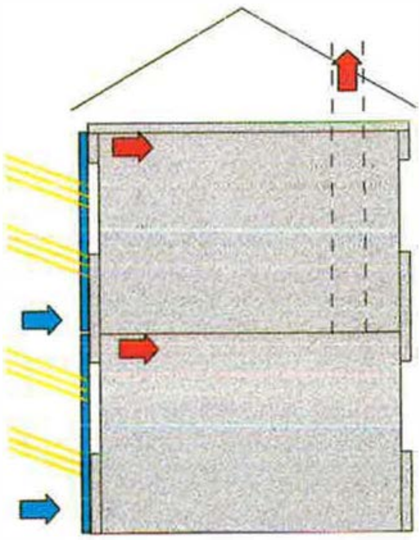
Water-based systems are preferably applied using roof-integrated collectors and a common water storage tank connected to a central DHW system. When suitable, the water-based system can also be connected to a central space heating system (typically hydronic radiators). However, it is also possible to connect roof-integrated or roof-mounted collectors to individual DHW systems (buffer storages), or to apply individual solar DHW systems.



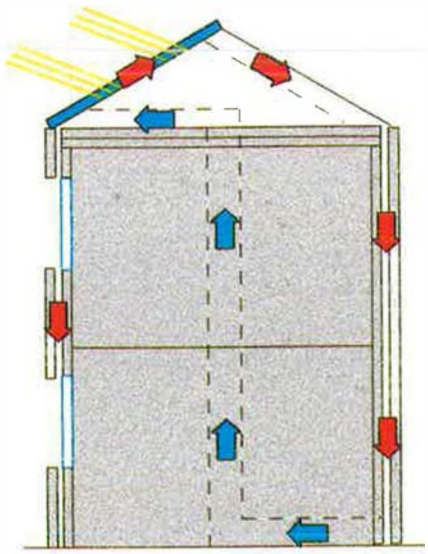
WATER-BASED COLLECTOR SYSTEM. SIMPLIFIED SYSTEM SCHEMATICS

Air-based collector systems

Air-based collector systems are primarily designed for preheating ventilation air or for space heating. When used for preheating ventilation air, the collectors are often placed on the facade close to where the fresh air enters the building. This results in short ducts, as well as higher efficiency during the space-heating period (favourable inclination at low solar angles). An air-based collector system is usually designed to make use of the building structure for heat storage, although separate storage elements are sometimes used. The use of a central air-handling system or a double-envelope facade also makes it suitable to use air-based collectors on the roof.



AIR-BASED COLLECTOR SYSTEM FOR PREHEATING VENTILATION AIR. SIMPLIFIED SYSTEM SCHEMATICS



AIR-BASED COLLECTOR SYSTEM AND DOUBLE-ENVELOPE FACADE. SIMPLIFIED SYSTEM SCHEMATICS

Solar Collectors

Collector design

A typical solar collector consists of an insulated enclosure, an absorber and a transparent cover (glass or plastic). Solar collectors can be more or less site-built or mounted using prefabricated modules, depending on the application.

Water-based collectors

There are several collector manufacturers, for example in Germany, Denmark, Sweden and Austria, which offer site-built collectors and manufacture large prefabricated module collectors (8–12 m²), suitable for renovation projects.

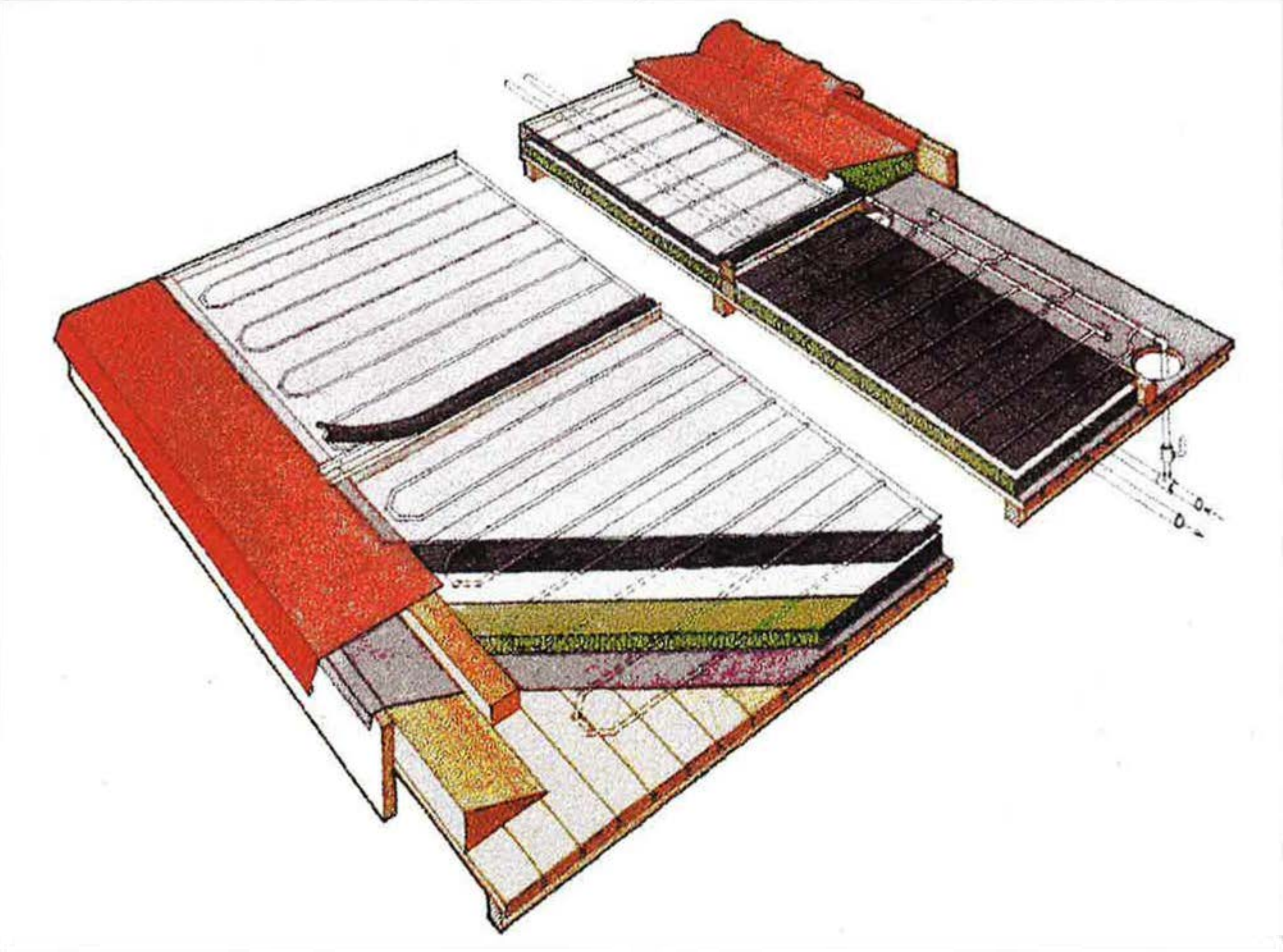
A recent development in Sweden is a prefabricated roof module with an integrated collector (see below). The roof module collector, 2.4 m wide, is designed to be mounted directly on the roof trusses. Similar products have also been developed in Germany. Self-builders in some countries also manufacture more or less site-built collector systems suitable for mounting on the roofing felt of multifamily buildings. The traditional small-module collectors (1–4 m²), manufactured by most collector manufacturers, are only suitable for individual systems (i.e. on individual or terraced houses).

Air-based collectors

There are only a few collector manufacturers that specialize in air-based systems. Most air-based collector systems used in renovation projects have so far been more or less special designs.

Key parameters

A solar collector may be characterized by two major parameters; the efficiency factor (η_0) and the thermal heat loss factor (U-value). The efficiency factor is typically between 0.6 and 0.8, while the heat loss factor varies from about 3 to 8 W/Km².



PREFABRICATED ROOF MODULE COLLECTOR (DEROME AB)

Architectural Considerations

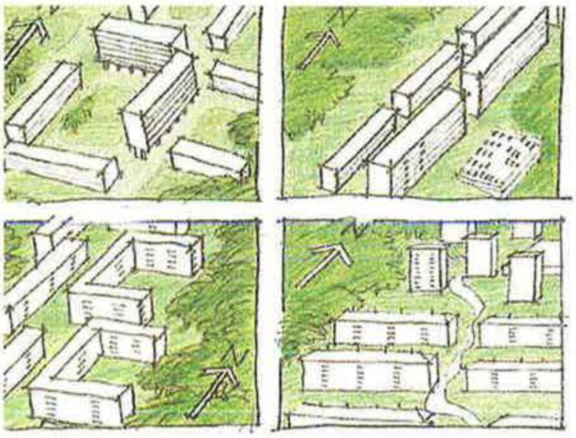
Solar collectors – an opportunity for the architect

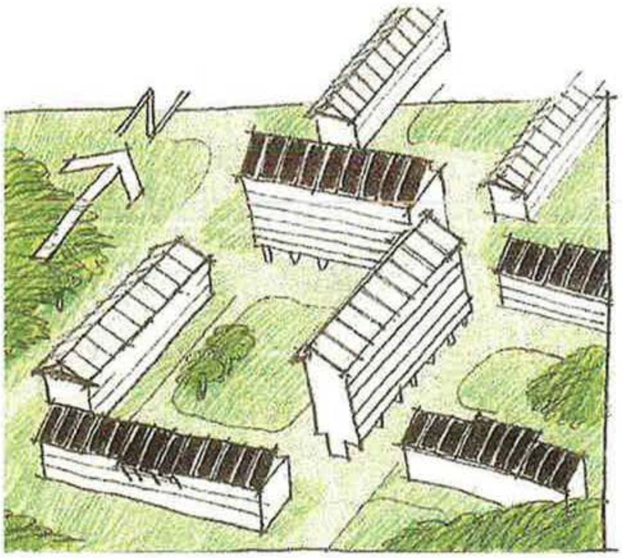
The outside of a building normally does not show how the building is heated. Maybe that is why architects pay less attention to the heating system, compared to other technical features such as protection against rain, wind, cold, etc. From this aspect, solar heating is an exception. Using solar collectors for water or air heating means that a part of the system, i.e. the solar collector, is placed on or in the building envelope.

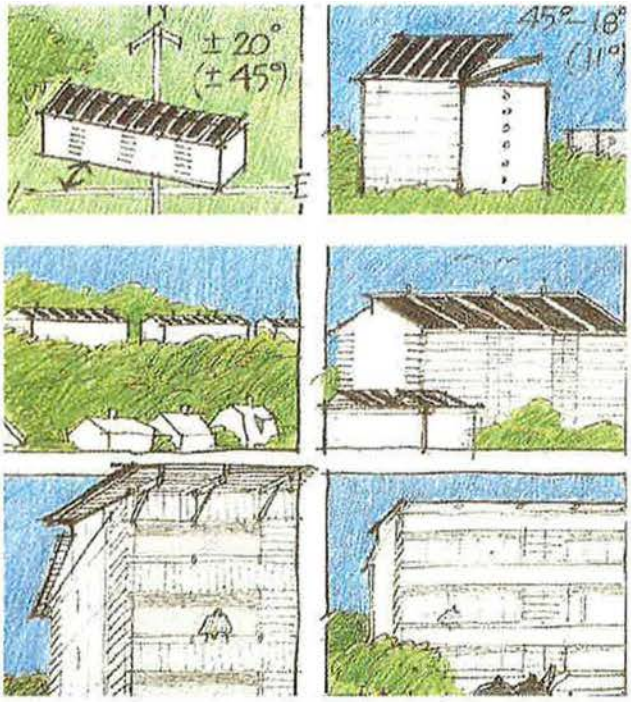
Building-integrated solar collectors thus provide the architect with a new architectural element for solving traditional renovation problems. In the following, some basic aspects of designing building integrated solar collectors are described. An existing building area, typical of 1970s construction, is used as an illustrative example. This type of building is often in great need of renovation. The roof may be leaking, the facades may be deteriorating, the heating system need to be renovated and the building appearance has to be improved.

A building-integrated solar collector can be used to solve several problems. As well as converting sunlight into useful heat, it can also replace roof and facade materials and be designed to give the building a new identity and character

The illustrations show roof-integrated solar collectors, since this type of building integration is most common. Collectors integrated in facades are also feasible, but here shading and facade design need to be considered in more detail.







Solar collectors should face south

The thermal output from collectors is influenced by orientation, inclination and shading. These factors must be considered during the design stage.

Roof orientations between south-east and south-west and most common roof inclinations are acceptable

Solar collectors are visible

There seems to be a common opinion that collector design is not very important, since collectors are most frequently placed on roofs. However, solar collectors can be very visible even as roof elements. Thus, collector design may have a large impact on the appearance of a building.

The collector surfaces may dominate the building's appearance. The smooth and reflecting surfaces (sometimes bright, sometimes dark) are easy to detect as they are different from common roofing materials. The appearance is very obvious if seen from a higher adjacent building. Details like roof eaves or gables are important at close range.

ROOF MODULE COLLECTORS IN ONSALA, SWEDEN

This photo shows a new building with prefabricated roof module collectors. The modules are developed so that they can be placed directly on the roof trusses, for example when a flat roof is rebuilt as an inclined one

ROOF-INTEGRATED (SITE-BUILT) COLLECTORS ON A MULTIFAMILY BUILDING IN GÖTEBORG (HAMMARKULLEN), SWEDEN

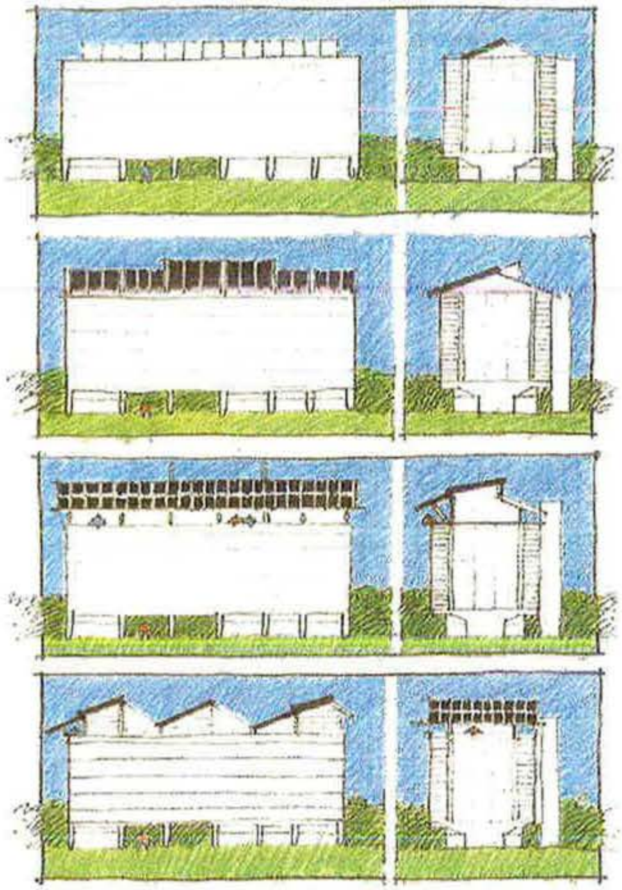
Solar collectors create space

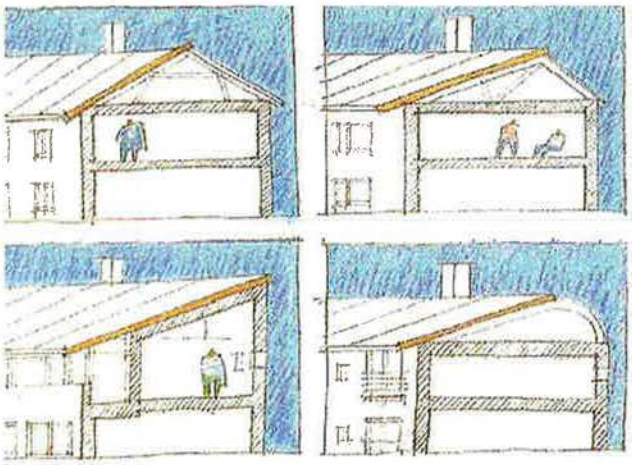
The thermal output from collectors is, as mentioned, influenced by orientation and inclination. However, there still remains considerable freedom of design. The collectors can be concealed or, on the other hand, they can emphasize the fact that the building uses solar energy.

The collectors can be placed at a distance from the roof eaves or hidden behind a roof edging, if the intention is to keep the original architectural appearance. They can be integrated in the roof without changing the form of the roof.

It is also possible to apply solar collectors on a new roof and create new spaces, e.g. in combination with new attic apartments. In this case, it is important to consider possible shading impacts on adjacent buildings.

ROOF-INTEGRATED COLLECTORS ON A MULTIFAMILY BUILDING IN NECKARSULM, GERMANY





Solar collectors form patterns

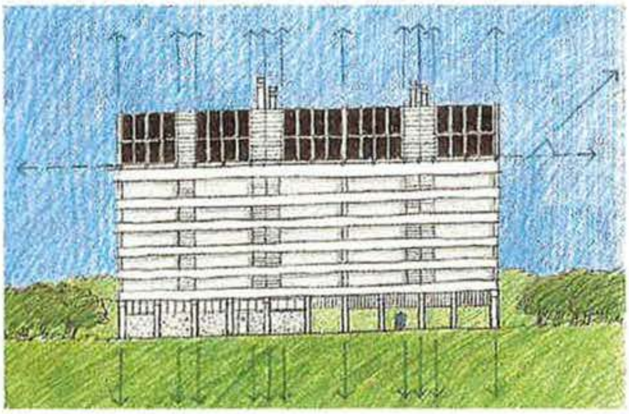
Vertical and horizontal partitions on collectors create patterns. The collectors can also create patterns together with other existing parts of the roof or the facade. These effects can be used either to create harmony with, or be in contrast to, existing patterns.

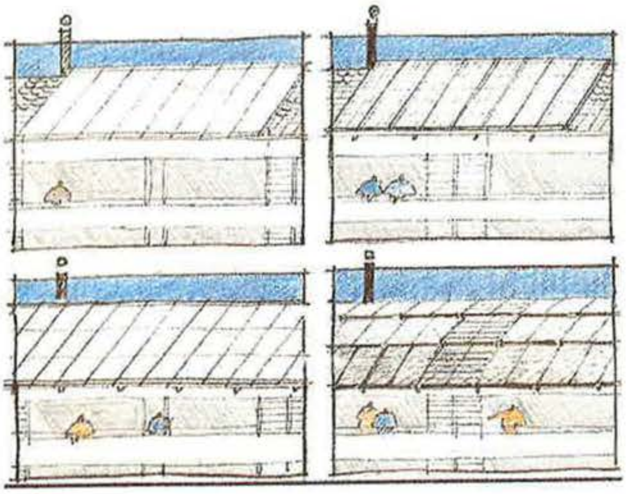
ROOF-INTEGRATED (MODULE) COLLECTORS ON A MULTIFAMILY BUILDING IN OEDERAN, GERMANY

Solar collectors have varying appearance

The collector surface has varying appearance depending on distance and time of day and year. Instead of the well known patterns and colours of traditional roofing materials, collector surfaces are smooth and reflect the surrounding buildings, the sky and the sun depending on the position of the viewer, the time of day and the season of the year.

The impression given by the surfaces will be different if the surfaces are positioned at different angles or are made of structured plastic or anti-reflective glass materials.





Other aspects

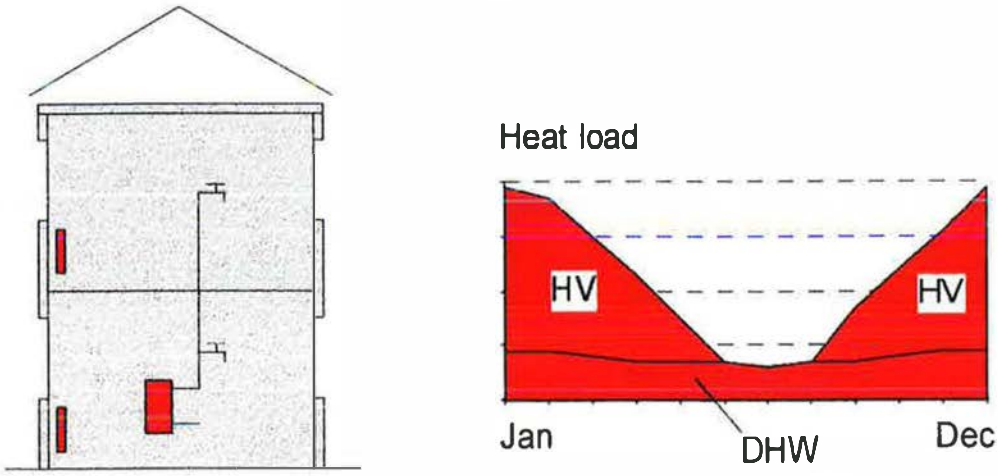
As well as the appearance, there are many other aspects that have to be considered when solar collectors are installed on a building. Form and function must be co-ordinated, as in any application. Snow and rain water must be able to drain away from the surface. Details like mountings, connections and pipes must be designed for reliable functioning and for an appropriate appearance, etc.

System Design

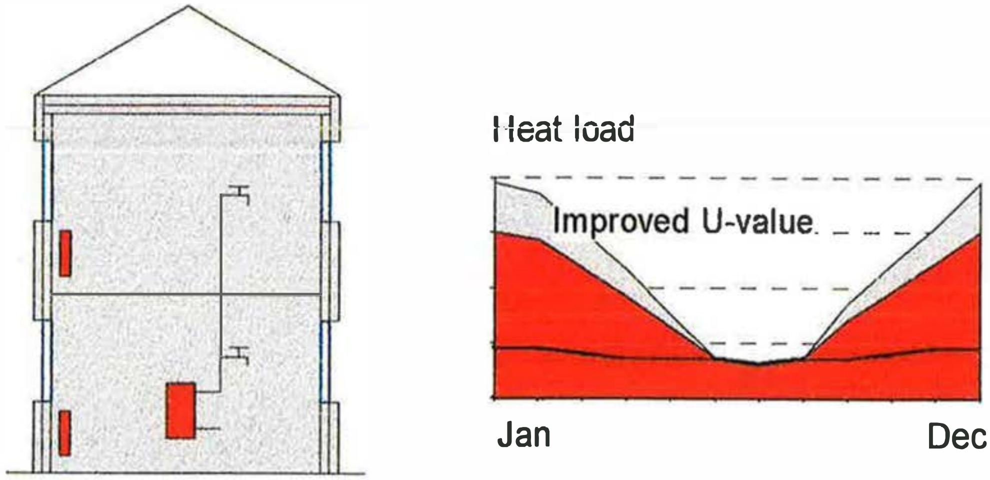
Reference case

In order to make possible a discussion about the specific energy benefits of a solar renovation concept, a reference case has to be defined. The following figure shows the principal thermal energy requirements in a typical multifamily building. The total annual heat requirement (heat supply) in this reference case is assumed to be about 40 kWh/m² of heated floor area for DHW and about 100 kWh/m² for HV.

The heat requirement for DHW is about the same in most countries, but the heat requirement for HV varies considerably with building type, design and location. A figure of 100kWh/m² is rather low for an old multifamily building that needs renovation. However, the intention here is to discuss the principal influence of solar renovation concepts. The diagrams below show the main effect of traditional renovation (energy conservation measures) on the annual heat requirement in the reference building, using opaque insulation and/or improved windows. These measures result in energy savings proportional to the improvement in the overall building U-value and in a slightly longer period without heat demand (not shown in the figure). The result is reduced thermal energy, as well as power, requirements.



ANNUAL HEAT REQUIREMENTS FOR HEATING, VENTILATION (HV) AND DOMESTIC HOT WATER (DHW) IN A TYPICAL MULTIFAMILY BUILDING – REFERENCE CASE



ANNUAL HEAT REQUIREMENTS FOR HV AND DHW AFTER TRADITIONAL RENOVATION (RED AREA) USING OPAQUE INSULATION AND IMPROVED WINDOWS

Preheating DHW

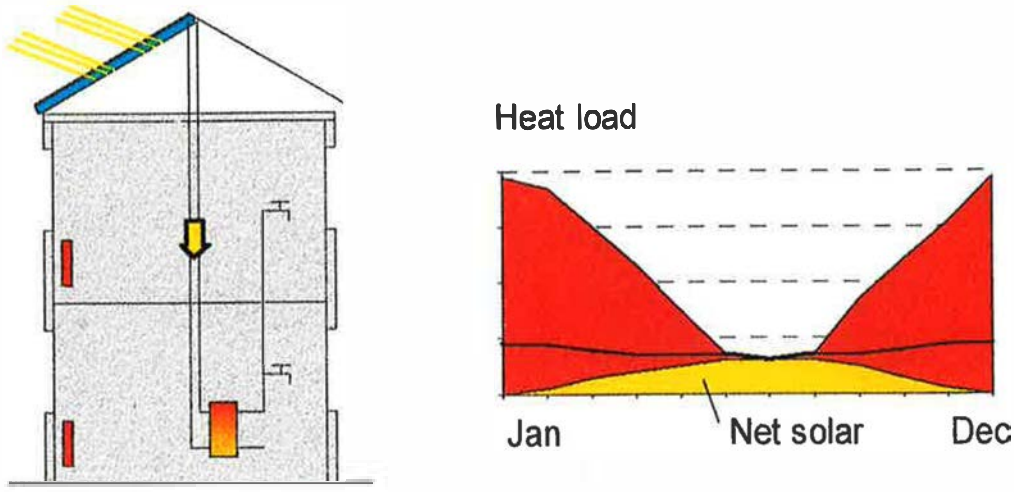
The main effect on the annual heat requirement of using solar collectors for preheating of DHW is shown in the following figure. Preheating of DHW will reduce the energy requirements for DHW heating during periods with solar radiation. However, the design thermal power requirements for DHW heating will be the same.

The solar system includes a water storage tank with a storage volume of 50 litres/m² collector area or about 200 litres per apartment.

The solar system is designed to cover the DHW during the summer period and/or about 40% of the annual requirements for DHW. The simple rule of thumb given opposite can be used to get a first estimate of the required system size:

ROOF-INTEGRATED SOLAR COLLECTORS

About 3–5 m² of collector area and 200 litres of buffer storage volume per apartment are required to meet 40–50% of the annual heat requirements for DHW



ANNUAL HEAT REQUIREMENTS FOR HV AND DHW AFTER INSTALLATION (RED AREA) OF A SOLAR DHW SYSTEM

If it is assumed that the annual DHW demand is typically 40 kWh/m² of heated floor area and a typical annual collector output is of the order of 400 kWh/m² of collector area, the thermal energy savings amount to 15–20 kWh/m² of heated floor area. This is valid for an average European or northern US climate and for a fairly good collector.

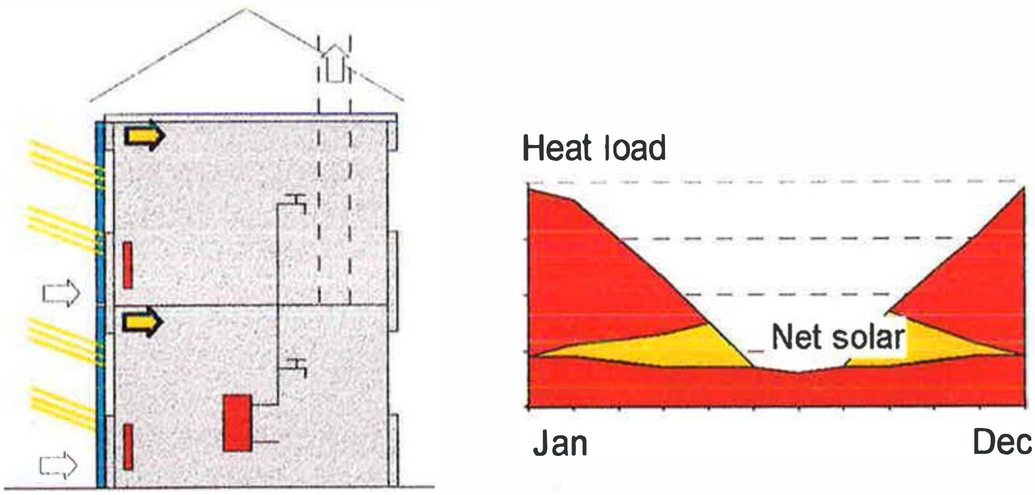
The space requirements for installation of a central solar heating system (pumps, heat exchangers, tank, etc.) are 6–10 m² of floor area per 100 m² of collector.

Preheating ventilation air

Most old residential buildings are naturally ventilated and applied energy conservation measures may introduce the need for a mechanical ventilation system, because the building envelope is made more airtight (reduced air infiltration). A common alternative is to apply a mechanical exhaust air system. The supply air can then be preheated in a solar collector.

The main effect of preheating ventilation air in a solar collector (e.g. in the facade) is shown in the figure. Preheating ventilation air will reduce the energy requirements for ventilation during periods with solar radiation. However, the design thermal power requirements for HV will be the same.

FACADE-INTEGRATED SOLAR COLLECTORS AND GLAZED BALCONIES



ANNUAL HEAT REQUIREMENTS FOR HV AND DHW AFTER RENOVATION (RED AREA) WITH PREHEATING OF VENTILATION AIR OR USING A SOLAR SPACE-HEATING SYSTEM

The following numbers can be used in a first estimate of the system size for a solar air system designed to cover part of the heat requirements for ventilation:

About 10 m² of collector area per apartment is required to cover 10–20% of the annual heat requirements for ventilation.

If it is assumed that a typical annual collector output is of the order of 150 kWh/m² of collector area (spring and autumn), the thermal energy savings amount to about 15 kWh/m² of heated floor area, with about 10 m² of collector area used per apartment. This is valid for an average European or northern US climate and for a fairly good collector.

In order to have a similar effect on the energy requirements for ventilation as for DHW, a collector area about three times larger is required. This is because solar preheating can only be utilized during periods when the outdoor air has to be heated (i.e. not summer).

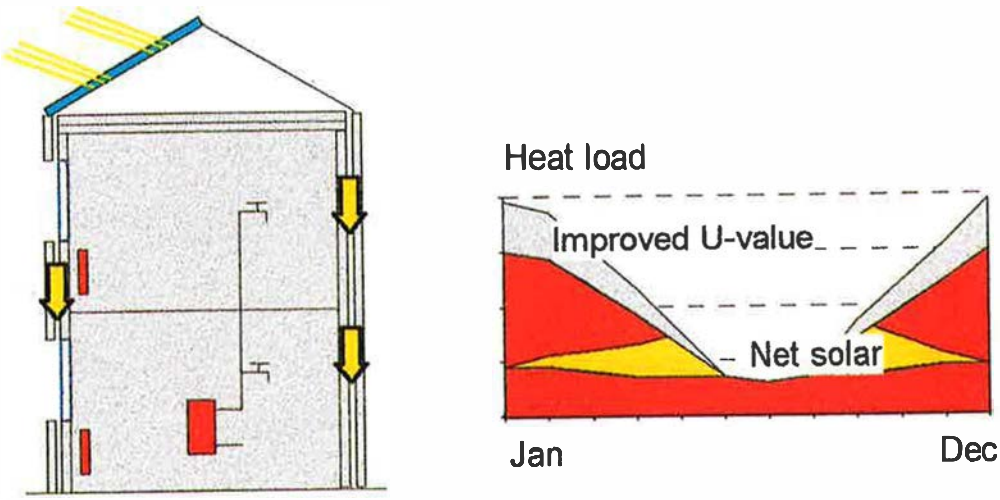
However, an air-collector system for preheating ventilation air may be made simpler than an water-collector system aimed at preheating DHW, resulting in a similar cost/performance ratio.

Space heating with a double envelope

A solar space-heating system with air collectors and a double envelope would have a similar influence on the energy requirements as that of preheating ventilation air. However, such a system must be installed together with new cladding and additional insulation.

The main effect of using air collectors and a double envelope (with an air gap) is shown in the figure. The solar air system will reduce the energy requirements for space heating during periods with solar radiation (yellow area), while the additional insulation will also reduce energy requirements for space heating, as well as the design thermal power requirements for space heating (grey area).

ROOF-INTEGRATED SOLAR COLLECTORS AND A DOUBLE ENVELOPE (AIR GAP)



ANNUAL HEAT REQUIREMENTS FOR HV AND DHW AFTER RENOVATION (RED AREA) WITH AIR COLLECTORS AND A DOUBLE ENVELOPE (INCLUDING NEW CLADDING AND ADDITIONAL INSULATION)

The following numbers can be used in a first estimate of the system size of a solar air system designed to cover a part of the heat requirements for space heating:

About 10 m² of collector area per apartment is required to meet 10–20 % of the annual heat requirements for heating

If it is assumed that a typical annual collector output is of the order of 150 kWh/m² of collector area (spring and autumn), the thermal energy savings amount to about 15 kWh/m² of heated floor area, with about 10 m² of collector area used per apartment. This is valid for an average European or northern US climate and for a fairly good collector.

In order to have a similar effect on the energy requirements for space heating as for DHW, a collector area about three times larger is required. This is because solar heating only can be utilized during periods with solar radiation and coincident demand for heat (i.e. not summer).

However, a central air-collector system for space heating may be combined with preheating of DHW during the summer period by introducing an air-to-water heat exchanger in the solar heating system.

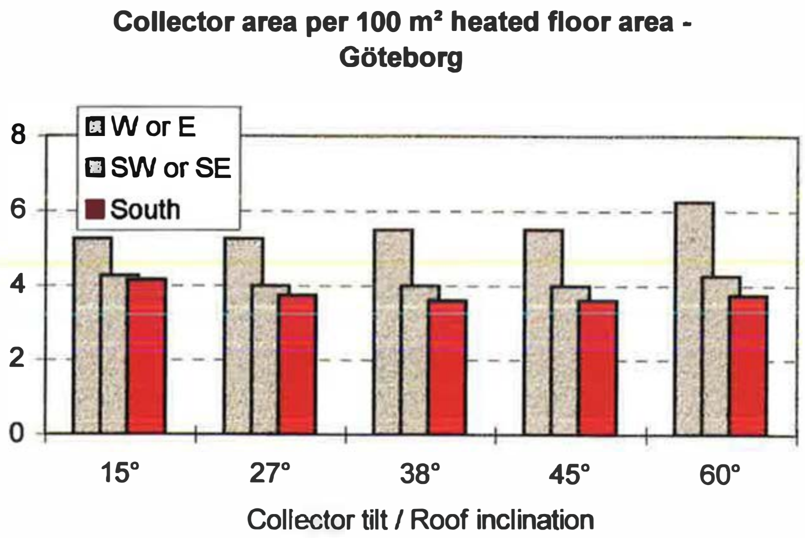
Collector area for preheating DHW

The following diagrams show the required collector area per 100 m² of heated floor area, depending on available roof (i.e. collector) orientation for Göteborg, Sweden (latitude 57°) and Freiburg, Germany (latitude 48°).

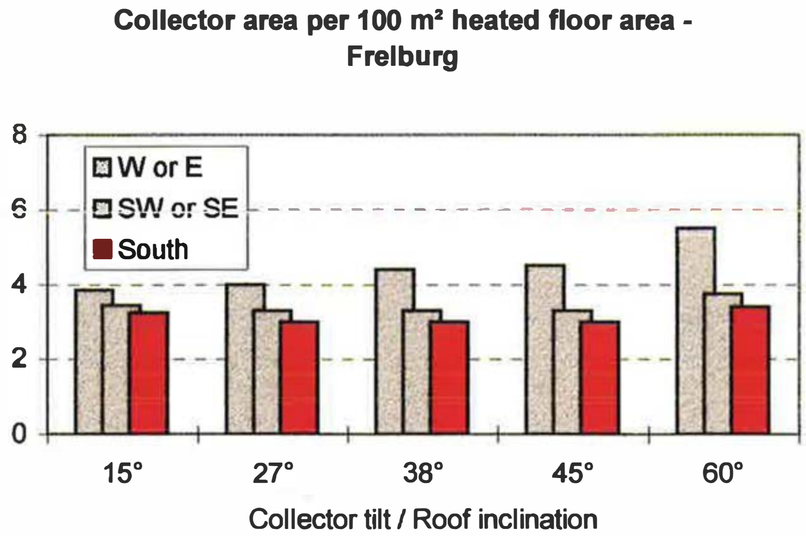
Depending on climate and collector orientation, the required collector area varies from 3 to 7 m² per 100 m² of heated floor area (approximately the floor area of an apartment).

A general conclusion is that roof orientations between south-east and south-west, together with roof inclinations between 15° and 45°, are suitable for collector mounting.

The calculations are based on a collector with an efficiency factor (η_0) of 0.75 and a heat loss factor (U value) of 3 W/Km², which is valid for existing high-performance collectors.



PREHEATING DHW UNDER TYPICAL CONDITIONS – REQUIRED COLLECTOR AREA PER APARTMENT IN GÖTEBORG, SWEDEN (LATITUDE 57°)



PREHEATING DHW UNDER TYPICAL CONDITIONS – REQUIRED COLLECTOR AREA PER APARTMENT IN FREIBURG, GERMANY (LATITUDE 48°)

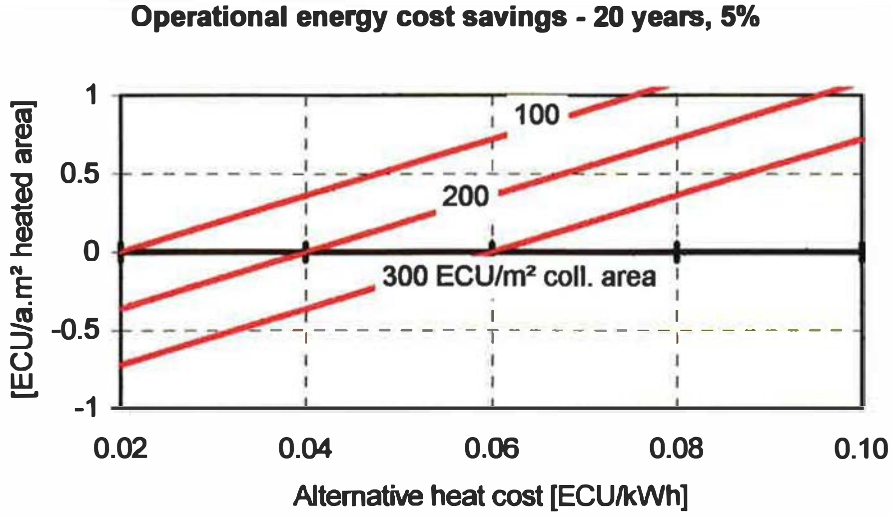
Economics

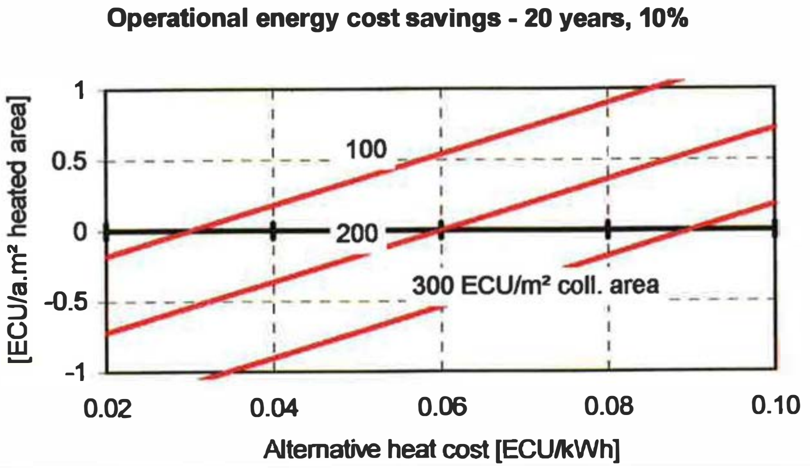
Preheating DHW

First, it should be noted that there are other benefits, in addition to energy cost savings, that can be gained by applying solar systems, e.g. environmental aspects. However, the following diagrams can be used to get a rough estimate of the cost-effectiveness of applying solar collectors for preheating DHW.

The cost-effectiveness of a system for preheating ventilation air and/or space heating is much harder to generalize since it is usually very system- and building-specific.

The diagrams show annual operational cost savings in ECU per m² of heated floor area in relation to marginal solar system investment cost in ECU per m² of collector area and alternative heat cost in ECU/kWh, i.e. the cost of displaced fuel, for different financial conditions. The cost-effectiveness of applying a solar system is very much influenced by financing conditions. Therefore, the energy cost savings are shown for 5% and 10% rates. The depreciation time is set at 20 years, but the lifetime of a high-quality collector is expected to be longer.





Present solar system investment costs are about 250 ECU/m² of collector area. Thus, the installation of a solar system may result in positive operational energy cost savings if the alternative heat cost is between 0.05 and 0.07 ECU/kWh, depending on the actual financing conditions.

The diagrams are based on a solar heating system meeting about 40% of the annual heat requirements for DHW, amounting to 40 kWh/m² of heated floor area per annum, and a net solar gain of 400 kWh/m² of collector area (i.e. for average European or northern US climate and for a fairly good collector).

Literature and Addresses

References

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Dalenbäck, J-O. and B. Ivarsson (1996). Roof Module Collector. Proceedings 4th European Conference on Solar Energy in Architecture and Urban Planning, Berlin, Germany.

IEA SHC Programme Task 20 publications

IEA SHC Programme 20 Brochures

- Solar Energy in Building Renovation
- Solar Collectors in Building Renovation
- Glazed Balconies in Building Renovation
- Transparent Insulation in Building Renovation

Developed under the Subtask on Dissemination, led by Chiel Boonstra, W/E Consultants Sustainable Building, The Netherlands.

Published by and available from:
James & James (Science Publishers) Ltd, 35–37 William Road, London NW1 3ER, UK
Email: james@jxj.com

IEA SHC Programme Task 20 Technical Reports

Subtask A: Evaluation of Existing Building Applications. 'Solar Energy in Building Renovation', Jan-Olof Dalenbäck, Building Services Engineering, Chalmers University of Technology, Göteborg, Sweden. Summary article published in Energy and Buildings 24 (1996) 39–50.

Subtask B: Improved Solar Renovation Concepts. Improved Solar Renovation Concepts, edited by André de Herde, Architecture et Climat, Louvain-la-Neuve, Belgium, 1997

Subtask C: Solar Renovation Demonstration Projects. Solar Renovation Demonstration Projects. Design of Solar Renovation Projects, edited by Olaf Bruun Jørgensen, Esbensen Consulting Engineers, Copenhagen, Denmark, 1997

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