Presentation of system performance calculation
Educational material

A technical report of subtask D

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IEA Solar Heating and Cooling Programme

The International Energy Agency (IEA) is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) based in Paris. Established in 1974 after the first “oil shock,” the IEA is committed to carrying out a comprehensive program of energy cooperation among its members and the Commission of the European Communities.

The IEA provides a legal framework, through IEA Implementing Agreements such as the Solar Heating and Cooling Agreement, for international collaboration in energy technology research and development (R&D) and deployment. This IEA experience has proved that such collaboration contributes significantly to faster technological progress, while reducing costs; to eliminating technological risks and duplication of efforts; and to creating numerous other benefits, such as swifter expansion of the knowledge base and easier harmonization of standards.

The Solar Heating and Cooling Programme was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia  Finland  Singapore  
Austria  France  South Africa  
Belgium  Italy  Spain  
Canada  Mexico  Sweden  
Denmark  Netherlands  Switzerland  
European Commission  Norway  United States  
Germany  Portugal  

A total of 49 Tasks have been initiated, 35 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities—Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops—have been undertaken.

Visit the Solar Heating and Cooling Programme website - www.iea-shc.org - to find more publications and to learn about the SHC Programme.
Current Tasks & Working Group:
Task 36  Solar Resource Knowledge Management
Task 39  Polymeric Materials for Solar Thermal Applications
Task 40  Towards Net Zero Energy Solar Buildings
Task 41  Solar Energy and Architecture
Task 42  Compact Thermal Energy Storage
Task 43  Solar Rating and Certification Procedures
Task 44  Solar and Heat Pump Systems
Task 45  Large Systems: Solar Heating/Cooling Systems, Seasonal Storages, Heat Pumps
Task 46  Solar Resource Assessment and Forecasting
Task 47  Renovation of Non-Residential Buildings Towards Sustainable Standards
Task 48  Quality Assurance and Support Measures for Solar Cooling
Task 49  Solar Process Heat for Production and Advanced Applications

Completed Tasks:
Task 1  Investigation of the Performance of Solar Heating and Cooling Systems
Task 2  Coordination of Solar Heating and Cooling R&D
Task 3  Performance Testing of Solar Collectors
Task 4  Development of an Insolation Handbook and Instrument Package
Task 5  Use of Existing Meteorological Information for Solar Energy Application
Task 6  Performance of Solar Systems Using Evacuated Collectors
Task 7  Central Solar Heating Plants with Seasonal Storage
Task 8  Passive and Hybrid Solar Low Energy Buildings
Task 9  Solar Radiation and Pyranometry Studies
Task 10  Solar Materials R&D
Task 11  Passive and Hybrid Solar Commercial Buildings
Task 12  Building Energy Analysis and Design Tools for Solar Applications
Task 13  Advanced Solar Low Energy Buildings
Task 14  Advanced Active Solar Energy Systems
Task 16  Photovoltaics in Buildings
Task 17  Measuring and Modeling Spectral Radiation
Task 18  Advanced Glazing and Associated Materials for Solar and Building Applications
Task 19  Solar Air Systems
Task 20  Solar Energy in Building Renovation
Task 21  Daylight in Buildings
Task 22  Building Energy Analysis Tools
Task 23  Optimization of Solar Energy Use in Large Buildings
Task 24  Solar Procurement
Task 25  Solar Assisted Air Conditioning of Buildings
Task 26  Solar Combisystems
Task 27  Performance of Solar Facade Components
Task 28  Solar Sustainable Housing
Task 29  Solar Crop Drying
Task 31  Daylighting Buildings in the 21st Century
Task 32  Advanced Storage Concepts for Solar and Low Energy Buildings
Task 33  Solar Heat for Industrial Processes
Task 34  Testing and Validation of Building Energy Simulation Tools
Task 35  PV/Thermal Solar Systems
Task 37  Advanced Housing Renovation with Solar & Conservation
Task 38  Solar Thermal Cooling and Air Conditioning

Completed Working Groups:
CSHPSS; ISOLDE; Materials in Solar Thermal Collectors; Evaluation of Task 13 Houses; Daylight Research
IEA Heat Pump Programme

This project was carried out within the Solar Heating and Cooling Programme and also within the Heat Pump Programme, HPP which is an Implementing agreement within the International Energy Agency, IEA. This project is called Task 44 in the Solar Heating and Cooling Programme and Annex 38 in the Heat pump Programme.

The Implementing Agreement for a Programme of Research, Development, Demonstration and Promotion of Heat Pumping Technologies (IA) forms the legal basis for the IEA Heat Pump Programme. Signatories of the IA are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the IA collaborative tasks or “Annexes” in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

The IEA Heat Pump Centre

A central role within the IEA Heat Pump Programme is played by the IEA Heat Pump Centre (HPC). Consistent with the overall objective of the IA the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Activities of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the IEA Heat Pump Programme and for inquiries on heat pump issues in general contact the IEA Heat Pump Centre at the following address:

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SE-501 15 BORÅS
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Visit the Heat Pump Programme website - http://www.heatpumpcentre.org/ - to find more publications and to learn about the HPP Programme.

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1 Introduction

IEA Task 44 / Annex 38 has produced free available educational material on the subject of performance figures evaluation for Solar plus Heat Pump (SHP) systems. The aim is to develop supporting material useful during teaching activities on the topic of Solar plus Heat Pump systems.

The content addresses the definition of several performance indicators developed within Task 44 / Annex 38. The material has been derived from the activities of Subtask B. More detailed information on this topic can be found in the deliverable B1. In the final slides an example is additionally presented for clarifying the relevance and the meaning of each single performance figure.

The material has a form of a presentation. Since the idea is to guide hand-in-hand the reader in the process of SHP analysis, the format is clear and communicative and clarifying text and graphs correlate indicator’s definition.

It is free downloadable from the Task 44 / Annex 38 webpage (http://task44.iea-shc.org).

2 Educational material

![Performance Figures calculation for Solar + Heat Pump systems](image-url)

Input from SubTask B

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Disclaimer

This presentation contains material collected and produced by participants to Task 44 / Annex 38 of the International Energy Agency (IEA) Solar Heating and Cooling Programme / Heat Pump Programme.

Performance Evaluation of SHP Systems

- Transparent and fair comparison of different SHP system configurations AND
- Comparison to other heating and cooling technologies
Seasonal Performance factor - SPF

The SPF gives the efficiency of the whole system or a defined subsystem, calculated as the overall useful energy output to the overall driving final energy input.

\[ SPF = \frac{\int (\dot{Q}_{\text{USE}} + \dot{Q}_{\text{ZERO}} + \dot{Q}_{\text{C}}) \, dt}{\int \sum P_{\text{D}} \, dt} \]

- Difficult to determine if system is operated simultaneously in different operation modes, e.g. heating and cooling, cooling and DHW etc.
- The SPF accounts for the system performance depending on the boundary conditions such as heat source temperature, solar irradiation, supply temperature etc.
- It does not take into account the depletion of non-renewables or CO₂ emissions caused during the lifetime etc.

SHP Reference System – Square View

Diagram showing the energy flow and components of a SHP reference system.
SHP Reference System - Simplifications

- Ambient and Exhaust Air, Ground Water, Ground and Waste Heat can all be considered as heat sources for the heat pump (\(Q_{in}\)) or heat sink in the case of free cooling or energy dissipation for active cooling. This, as well as the respective heat exchangers, are put together as “free energy sources” with an orange frame (dashed for heat exchangers).
- Solar collectors can generally transform both solar radiation and ambient air heat (including conduction) into useful heat or heat source for the heat pump (either directly or for the regeneration of the ground, air, or heating etc.). This fact has been considered by putting Air and Sun together with the yellow frame. The energy input to the collector is denominated as \(Q_{solar}\) for the solar collector input and \(Q_{ambient}\) for the energy input from the ambient air.
- Treated energy includes Electricity and other energy carriers, denominated by “Energy carrier”.
- Energy flows are represented in their physical direction, from higher to lower temperatures.
- The connections between the components do not reproduce the hydraulic configuration of the system. However, provide information on possible interactions between the components, due to the hydraulics and the controls of the system.

- The connections between components with a pump symbol represent energy consumption needed to transport the heat transfer medium and overcome the pressure losses within the system.
- The components presented with a dashed frame (both storages) can be ignored if not a part of a particular system or if direct connections possible (e.g., the solar energy can be either stored or used directly in the evaporator of the heat pump).
- Although presented as one component, the “storage” can actually consist of more than one unit (e.g., one storage for heating and one for DHW). This implies, that e.g., the energy input \(Q_{storage}\) can in reality consist of more than one consumer (pumps).
- In analogy, one pump can be used to transport the heat transfer medium e.g. from one “heat source” component to several “heat sink” components. For example, one pump can be used to circulate the fluid from the collector both to the evaporator of the heat pump and to the heat storage. This implies, that this pump would be consuming both \(P_{evap}\) and \(P_{storage}\). This has to be considered for the evaluation of the data accordingly.
- Defrosting for air source units:
  - Direct electric defrosting: Should be included in \(P_{evap}\)
  - Hot gas defrosting: The energy consumption should also be included in \(P_{evap}\)
  - Reverse cycle defrosting: The heat energy taken from the storage/building has to be subtracted from the useful energy output at the appropriate boundaries, if not automatically executed by the heat meter.

System Boundaries

Four different boundaries have been defined to evaluate a SHP system:

1. „SHP+“ Solar and Heat Pump System with Useful Energy Distribution System
   a. Systems without additional heating of the distribution pipes
   b. Systems with additional heating of the distribution pipes
2. „SHP“ Solar and Heat Pump
3. „bSt“ Before Storage
4. „HP + HS (HR)“ Heat Pump with Heat Source (Heat Rejection)
5. „HP, SC, BU“ Heat Pump, Solar Collector, Back-Up Unit
System Boundaries – SHP+

\[
SPF_{\text{HPP}} = \frac{\left[ \dot{Q}_{\text{in}} + \dot{Q}_{\text{out}} + \dot{Q}_{p} \right]}{\left( \sum P_{\text{HPP,ex}} \right)} \text{ at } \frac{\sum P_{\text{HPP,ex}}}{\left( \sum P_{\text{HPP,ex}} \right)} \text{ at }
\]

System Boundaries – SHP

\[
SPF_{\text{HPP}} = \frac{\left[ \dot{Q}_{\text{in}} + \dot{Q}_{\text{out}} + \dot{Q}_{p} \right]}{\left( \sum P_{\text{HPP,ex}} \right)} \text{ at } \frac{\sum P_{\text{HPP,ex}}}{\left( \sum P_{\text{HPP,ex}} \right)} \text{ at }
\]
System Boundaries – bSt

\[ SPF_{\text{bSt}} = \frac{\left| Q_{\text{in, bSt}} + Q_{\text{in, aux}} + Q_{\text{in, aux}} + Q_{\text{in, aux}} \right|}{\left| \sum P_{\text{in, aux}} \right|} \]

\[ \sum P_{\text{in, aux}} = P_{\text{HP}} + P_{\text{cool}} + P_{\text{aux}} + P_{\text{aux}} + P_{\text{aux}} + P_{\text{aux}} + P_{\text{aux}} + P_{\text{aux}} \]

System Boundaries – HP + HS

\[ SPF_{\text{HP+HS}} = \frac{\left| Q_{\text{in, HP+HS}} + Q_{\text{in, aux}} + Q_{\text{in, aux}} + Q_{\text{in, aux}} \right|}{\left| \sum P_{\text{in, aux}} \right|} \]

\[ \sum P_{\text{in, aux}} = P_{\text{HP}} + P_{\text{cool}} + P_{\text{aux}} + P_{\text{aux}} + P_{\text{aux}} + P_{\text{aux}} + P_{\text{aux}} + P_{\text{aux}} \]
System Boundaries – HP / SC / BU

\[
SPF_{SC} \text{ and } SPF_{BU} \text{ analog to } SPF_{HP}
\]

\[
SPF_{\text{HPP}} = \frac{\int (Q_{\text{HP}} + Q_{\text{SC}}) \, dt}{P_{\text{HP}} \, dt}
\]

Overall

\[
SPF_{\text{HPP, lev}} = \frac{\int Q_{\text{HP}} \, dt}{P_{\text{HP}} \, dt}
\]

Heating Mode

\[
SPF_{\text{HPP, cool}} = \frac{\int Q_{\text{HP}} \, dt}{P_{\text{HP}} \, dt}
\]

Cooling Mode

Example – Simplified Hydraulic View
Example – Square View Representation

Example – Square View Representation with Quantities
Example – SPF according to the respective boundary

- SPF – SHP+

\[
SPF_{\text{SHP+}} = \frac{\int (Q_{\text{out}} + Q_{\text{comp}}) \, dt}{\int \left( \sum P_{\text{A}} \right) \, dt}
\]

\[
SPF_{\text{SHP+}} = \frac{11500 + 2700}{4550}
\]

\[
\int \left( \sum P_{\text{A}} \right) \, dt = 350 + 150 + 100 + 300 + 2000 + 300 + 300 + 150 + 600
\]

SPF_{SHP+} = 3.12

Example – SPF according to the respective boundary

- SPF – SHP

\[
SPF_{\text{SHP}} = \frac{\int (Q_{\text{out}} + Q_{\text{comp}}) \, dt}{\int \left( \sum P_{\text{A}} \right) \, dt}
\]

\[
SPF_{\text{SHP}} = \frac{11500 + 2700}{4100}
\]

\[
\int \left( \sum P_{\text{A}} \right) \, dt = 350 + 150 + 100 + 300 + 2000 + 300 + 300 + 600
\]

SPF_{SHP} = 3.46
Example – SPF according to the respective boundary

### SPF – bSt

\[
\text{SPF}_{\text{bSt}} = \frac{\int (\dot{Q}_{\text{in}} + \dot{Q}_{\text{out}}) \, dt}{\int (\sum \dot{P}_{\text{in},\text{bSt}}) \, dt}
\]

\[
\sum \dot{P}_{\text{in},\text{bSt}} = \dot{P}_{\text{EV,C}} + \dot{P}_{\text{EV,H}} + \dot{P}_{\text{EV,HE}} + \dot{P}_{\text{EV,HE}} + \dot{P}_{\text{EV,HE}}
\]

\[
\text{SPF}_{\text{bSt}} = \frac{4800 \times 10200}{3500} = 4.29
\]

### SPF – HP+HS

\[
\text{SPF}_{\text{HP+HS}} = \frac{\int (\dot{Q}_{\text{in}} + \dot{Q}_{\text{out}}) \, dt}{\int (\sum \dot{P}_{\text{in},\text{HP+HS}}) \, dt}
\]

\[
\text{SPF}_{\text{HP+HS}} = \frac{10200}{2000 + 150 + 300 + 300} = 4
\]
Example – SPF according to the respective boundary

- SPF – HP and SC

\[
SPF_{HP} = \frac{\int \dot{Q}_{HP} \, dt}{\int \dot{m}_{HP} \, dt}
\]

\[
SPF_{HC} = \frac{\int \dot{Q}_{HC} + \dot{Q}_{SC} \, dt}{\int \dot{m}_{HC} \, dt}
\]

\[
SPF_{HP} = \frac{10200}{2000} = 5.1
\]

\[
SPF_{HC} = \frac{4800 + 150 + 100}{350} = 14.42
\]

Example – comparison of different SPF:

[Bar chart showing comparison of different SPF values]

Corresponding Boundary

SPF

SC

HP

HP + HS

St

SHP
## Nomenclature

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>CED</td>
<td>Cumulative Energy Demand</td>
</tr>
<tr>
<td>E</td>
<td>Energy flux in W</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
<td>I</td>
<td>Solar Irradiation in W</td>
</tr>
<tr>
<td>P</td>
<td>Power in W</td>
</tr>
<tr>
<td>Q</td>
<td>Thermal power in W</td>
</tr>
<tr>
<td>PER</td>
<td>Primary Energy Ratio</td>
</tr>
<tr>
<td>SPI</td>
<td>Seasonal Performance Factor</td>
</tr>
</tbody>
</table>

**Subscripts, capital**

- BU: Back-up unit
- C: Cooling, low temperature
- Cool: Cooling operation
- CU: Control unit
- DHW: Domestic hot water
- FE: Final energy
- H: High temperature
- Heat: Heating operation
- HP: Heat pump
- HR: Heat rejection
- NRE: Non-renewable
- PE: Primary energy
- SH: Space heating
- SHP: Solar and heat pump
- SHP+: Solar and heat pump plus energy distribution system

**Subscripts, small**

- BS: Before storage
- el: Electrical
- col: Collector(s)
- Rad: Radiative