IEA SHC Task 66: Solar Energy Buildings

Integrated solar energy supply concepts for climate-neutral buildings and communities for the "City of the Future"

Design, construction and operation of a solar thermal family home

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22. December 1972 / married / 2 children

Exergenion // Engineering Consultant (Prien am Chiemsee)
2015  Self-employed consultant

Alstom Switzerland AG (Baden)
2013 – 2015  R&D Program Manager – Combined cycle gas turbine power plants
2007 – 2013  Team Leader – Heavy duty gas turbine development
2006 – 2007  R&D Project Manager – Heavy duty gas turbine development
2005 – 2006  Product Manager – Heavy duty gas turbines
2002 – 2005  Performance Test Engineer

Bertrandt AG (Munich)
2000 – 2002  BMW engine application and Performance Test Engineer

Technical University Munich TUM
Summary

• Energy storage is key for Solar Energy Buildings

• Storage also means being flexible to buy external energy when it is available and less costly

• For heating purposes, the energy should be stored as sensible heat, not electricity
  • When the sun is shining, heat is stored for later
  • But in future heat will also be stored when electricity tariffs are low

• Heat storage tanks are most profitable if sized for anything between 12 and 48 hours of wintertime storage without the need of external heat input

• Currently electric mobility with small commuter cars generates the highest savings to finance a Solar Energy Building (at least for Germany)

• Vertical thermal collectors are a perfect match with roof top PV
  Ŷ Low stagnation temperatures in summer (<90°C), easy to integrate, high performance in winter, low-cost technology
Overview

• 5 years in a highly self-sufficient solar home
• Design and construction
• Energy storage
• Construction
• Economics and conclusions
European building energy certificate

Not a passive house, but efficient

Building dimensions 11.3 m x 9 m
Basement, ground, 1st & 2nd floor

<table>
<thead>
<tr>
<th>Energiebedarf</th>
<th>CO₂-Emissionen³</th>
<th>0 kg/(m²·a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endenergiebedarf dieses Gebäudes</td>
<td>32 kWh/(m²·a)</td>
<td></td>
</tr>
<tr>
<td>Primärenergiebedarf dieses Gebäudes</td>
<td>6 kWh/(m²·a)</td>
<td></td>
</tr>
</tbody>
</table>

Anforderungen gemäß EnEV⁴

<table>
<thead>
<tr>
<th>Primärenergiebedarf</th>
<th>Anforderungswert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ist-Wert 6 kWh/(m²·a)</td>
<td>56 kWh/(m²·a)</td>
</tr>
</tbody>
</table>

Energetische Qualität der Gebäudehülle Hₚ

<table>
<thead>
<tr>
<th>Ist-Wert</th>
<th>Anforderungswert</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.19 W/(m²·K)</td>
<td>0.37 W/(m²·K)</td>
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</tbody>
</table>

Sommerlicher Wärmeschutz (bei Neubau)

☐ eingehalten

Für Energiebedarfsberechnungen verwendetes Verfahren

☐ Verfahren nach DIN V 4108-6 und DIN V 4701-10
☑ Verfahren nach DIN V 18599
☐ Regelung nach § 3 Absatz 5 EnEV
☐ Vereinfachungen nach § 9 Absatz 2 EnEV

Ingenieurbüro Exergenion
Energietechnik
Energieberatung

[Diagram showing energy efficiency ratings and calculations]
Location

5km north of the alps

Common PV yield 1’200 kWh/kWp
Average ambient temperature 8,9°C
Building systems:

Heat
32 m² thermal collectors – south facade
24 kW log boiler located in living room
Stratified boiler tank 4’700 liters
Floor heating

Electricity
PV roof south 10 kWp
PV carport west 4 kWp

Battery storage 29 kWh
Electric vehicle 32 kWh (non bidirectional)

Other:
Rainwater storage
2 separate central ventilation systems
Energy demand 1

Electric energy

• Household (2 adults, 2 children):  
  • 3’250 kWh\text{el}

• Office - Exergenion (2\text{nd} floor)  
  • 550 kWh\text{el}
  • 5’000 km electric car – 16 kWh/100km – 800 kWh\text{el}

• Commuting distance 2 x 35km – 5 days/w
  • 13’000 km electric car – 16 kWh/100km – 2’100 kWh\text{el}

\[ \Sigma \quad 6’700 \text{ kWh}_\text{el} \]
Annual Electric - Energy Balance

PV
- internal consumption 35%
- solar savings fraction 82%

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Amount (kWh$_{el}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>6'700</td>
</tr>
<tr>
<td>Battery</td>
<td>2'950</td>
</tr>
<tr>
<td>PV production</td>
<td>15'750</td>
</tr>
<tr>
<td>Grid export</td>
<td>10'250</td>
</tr>
<tr>
<td>Grid import</td>
<td>1'200</td>
</tr>
</tbody>
</table>

Incorporating internal consumption and solar savings fraction:

- Internal consumption 35%
- Solar savings fraction 82%
Energy demand 2

Heating and hot water

- Direct heating – floor heating
  - 7’400 kWh\textsubscript{th}

- Indirect heating – usable heat losses from storage tank (in winter)
  - 1’900 kWh\textsubscript{th}

- Indirect heating – convection and radiation from log boiler
  - 400 kWh\textsubscript{th}

- Hot water
  - 1’950 kWh\textsubscript{th}

\[ \sum 11’650 \text{ kWh}\textsubscript{th} \]
Annual Heating - Energy Balance

Solar thermal
- solar savings fraction 65%

Input (wood) 5’500 kWh

Wood fired central-heating boiler

Convection & radiation 400 kWh

Water 3’700 kWh

Storage tank

Demand 11’650 kWh

Solar thermal 9’550 kWh

Solar thermal input 7’550 kWh

Exhaust gas losses 1’400 kWh

Excess heat (in summer) 2’100 kWh
CO₂ Balance

**Biomass 5’500 kWh (0,027 kg CO₂/kWh)**
- 75 % wood logs as by-product from local forest management
- 25 % wood briquettes from a local sawmill

**Electricity (0,434 kg CO₂/kWh)**
- 1’200 kWh grid import
- 10’250 kWh grid export

**Biomass**
150 kg (fossil) CO₂ emissions

**Electricity**
- Import 520 kg CO₂ emissions
- Export -4’450 kg avoided CO₂

Total CO₂ emissions from building operation and electric mobility

minus 3,8 tons CO₂
Overview

• 5 years in a highly self-sufficient solar home

• Design of solar systems

• Energy storage

• Construction

• Economics and conclusions
Design tools

Input creation for solar simulations
• Solar site assessment with shade measurement tools
• Proper evaluation of energy demand
  - Hot water demand
  - Electric consumers
  - E-Mobility and charging behavior (day/night)
• Building simulation

Solar simulations
• PV simulations (here pV*Sol)
• Energy system simulation (here Polysun)

A properly calibrated toolset and experience is needed for reliable results.
Simulations and reality

Heat – solar savings fraction

Building simulation: 69%
Data recording: 65%

Electricity - solar savings fraction

PV simulation: 87%
Data recording: 82%
Overview

• 5 years in a highly self-sufficient solar home

• Design of solar systems

• Energy storage

• Construction

• Economics and conclusions
Energy storage

Heat
Heat storage costs - 1 kWh$_{th}$ approx. 25 - 50€

For the house presented a maximum capacity of 350 kWh$_{th}$ of which 200 kWh$_{th}$ are usually used.

Electricity
Electricity storage costs - 1 kWh$_{el}$ approx. 300 - 500 €

In the house presented
29 kWh$_{el}$ battery storage
32 kWh$_{el}$ electric car
Overview

• 5 years in a highly self-sufficient solar home
• Design of solar systems
• Energy storage
• Construction
• Economics and conclusions
Construction

Mix of different construction methods:

- Basement – thermal insulated concrete
- Ground and 1st floor – solid construction filled with perlites
- South front - solid construction filled with perlites plus wood fiber ETICS
- 2nd floor and roof – timber frame construction
Construction

Building integrated solar technology

- Rooftop PV with in-roof look
- Built-in thermal collectors
Construction

Building integrated solar technology

- Stratified boiler tank from basement to top of ground floor to make use of convection heat losses
Construction

Stratified boiler tank
- 20cm efficient insulation
- The top ends in the kitchen
Highly modularized components

Nonintegrated design:
- Only components that fail must be individually replaced
Construction

Log boiler
- Low emissions – 2 stage combustion
- 90% heat transfer to water cycle
- Low convection
- Low heat radiation
Integration of solar systems
Completion
Overview

- 5 years in a highly self-sufficient solar home
- Design of solar systems
- Energy storage
- Construction
- Economics and conclusions
Additional investments (2018)

Building extra costs compared to German standard in 2018
- Insulation: + 5’000 €
- Engineering: + 15’000 €

Extra costs for components compared to a natural gas boiler
- Hardware: + 60’000 €
- Engineering: + 10’000 €

Subsidies: - 40’000 €

Total extra cost: + 50’000 €

- Annual savings heating: - 950 €
- Annual savings mobility: - 1’850 €
- Annual savings electricity (w/o car): - 1’300 €

Actual annual savings: - 3’750 €

Break-even at actual energy prices: 13 ... 14 years
Conclusion

Advantages of a highly self-sufficient solar home concept

- Operation of the building is CO$_2$ negative
- Living and mobility are highly independent from energy prices
- Predictable investment and energy costs
- Local value creation:
  - Building and energy components sourced entirely from Austria and Germany (with exception of Li-On batteries)
- Operation of the building in combination with e-mobility shows no resulting energy costs until 2039 (due to feed in tariffs)

Instant savings instead of risking high costs from burning fossil fuels

And the pleasure of living in a CO$_2$ negative building.
Thank you for your attention