Energy Research Lab (ERL) – Institute of Energy in Building, FHNW

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1.1 General Presentation

The Energy Research Lab (ERL) was built in 2013 to test and optimize components for heat and power supply systems in buildings. Testing may focus on the individual performance of a component or its role within an entire system. While heat pumps are most often the central point of interest, evaluation has also included phase-change storage, solar-thermal collectors, complex valves and control systems. Recently, photovoltaics and batteries have been of increasing importance in the ongoing research. In addition to the strictly physical experiments, components are regularly operated in interaction with numerical models, extending the scientific range to systems beyond the confines of the laboratory.

1.2 Description of the Test Facility

1.2.1 The Thermodynamic Core

The functional core of the laboratory is a 2-stage system, capable of dynamically supplying multiple test components with temperature-controlled water. The first stage consists of two 1600 L tanks (6) with hot and cold water, which are connected by one heat pump, simultaneously heating and cooling the corresponding sides. An energy dissipater on the hot side provides a second degree of freedom to regulate the temperatures in the tanks.

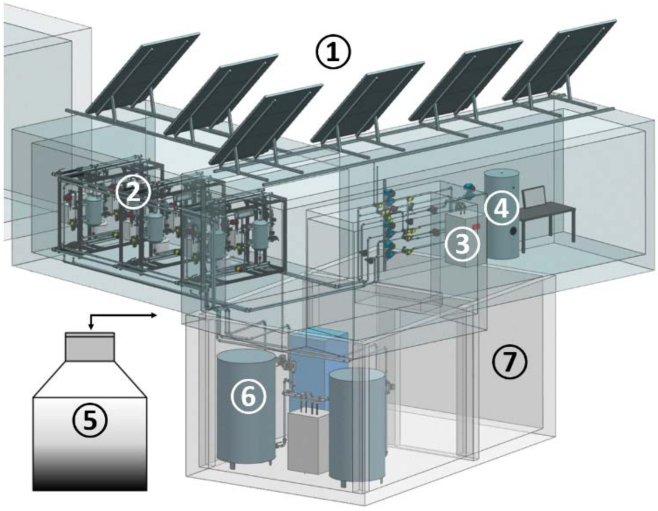


Figure 1. (1) Photovoltaics (2) Thermodynamic core stage 2 (3) Heat pump (4) Domestic hot water storage (5) Phase-change storage (6) Thermodynamic core stage 1 (7) Climate chamber

Supplied by the first stage, the second stage consists of three pairs of smaller hot- and cold-side tanks (2). Two of these pairs contain water. The third pair contains a water-glycol mixture. The purpose of these smaller tanks is to provide quick buffer capacity for generating the desired input profiles for test components. Furthermore, the temperature difference between these pairs is smaller than the temperature difference between the big tanks, allowing for easier and more accurate power control.


Figure 2. Second stage of the thermodynamic core (left). Heat pump and domestic hot water storage (right).

Thermodynamic Core: Specifications		
Max. mass flow	L/h	6000
Max. power	kW	16
Temperature range	°C	-10…90

In application, this system is used to emulate sources and sinks, such as geothermal heat exchangers, solar-thermal collectors or room heating. The output values for the emulated components are generated through numerical simulation. The physical outputs are then fed to real test components, such as heat pumps (3) or domestic hot water storage (4), shown in Fig. 3.

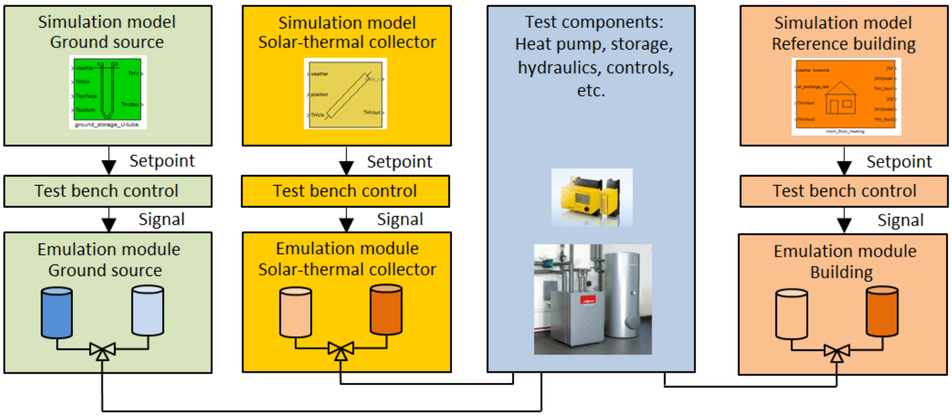


Figure 3. Second stage of the thermodynamic core with emulation models and real test components

1.2.2 Climate Chamber

A climate chamber (7) has been added to the laboratory in 2015 and is used to condition air for testing air-fed heat pumps. Thus, it can be thought of as an extension of the thermodynamic core. Additionally, the climate chamber can be used to study frosting and defrosting on the external heat exchanger and their effect on the performance of the heat pump.

Climate Chamber: Specifications		
Max. air volume	m^3/h	3500
Temperature range	°C	-20…40
Humidity range	%	15…98

external unit of split heat pump.

1.2.3 Phase-Change Storage

The laboratory is equipped with a 10 m^3 water-based phase-change storage (5) from Viessmann/Isocal. The state of the storage can be measured with a total of 41 temperature sensors. Of those, 21 are located inside the storage, 18 in the earth on its sides and two in the earth below. If needed, the storage could be filled with an alternative fluid, such as paraffin oil or a glycol solution. This would change the melting/freezing point (i.e. operating point) of the storage as well as its capacity.

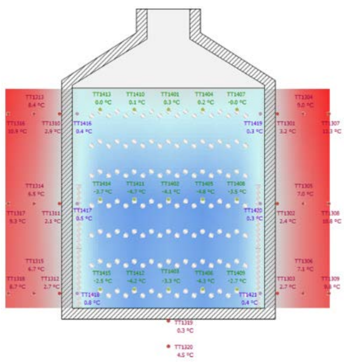


Figure 5. Phase-change storage

1.2.4 Electric Installations

PV Emulator: Specifications		
Max. power	kW	10
Max. voltage	V	600
Max. current	A	20

In order to extend the research capabilities for household electric systems, a highly instrumented electric distributor with connections for a photovoltaic system, heat pump, battery and household appliances has been installed. While a real photovoltaic system is available in the laboratory, its dependence on the weather makes it unsuitable for reproducible, standardized testing. Therefore, a photovoltaic emulator (Regatron “TopCon Quadro”) has been added to the electric setup. On the demand side, an electric load emulator with up to 8 kW and thermal energy recovery has been installed in the laboratory. Unlike real household appliances, this allows the execution of defined load profiles. It also requires significantly less space. With this setup, control strategies for electric power management can be investigated.

1.2.5 Sensors and Data Acquisition

The laboratory features a range of sensors for solar radiation, wind speed and ambient temperature. Additionally, the various technical installations and test components contain a large number of sensors, mostly measuring temperatures, flows and electric powers. These sensors feed into event-driven database logging through a self-developed SCADA (Supervisory Control and Data Acquisition) system, which supports all common industrial bus systems. The hardware components were mostly supplied by National Instruments.

1.2.6 Simulation

The primary software used for simulations is Matlab/Simulink in combination with the CARNOT Blockset Toolbox, which offers a wide array of standard components, ranging from controllers and valves to entire buildings. CARNOT’s open source nature is frequently used to modify existing components to fit individual requirements and to add additional component models to the toolbox.

CARNOT Blockset Features (selection)	
• Hydraulics	• Solar-thermal collectors
• Pneumatics	• Geothermal systems
• Heat pumps	• Combustion heaters
• Control systems	• Thermal house models
• Thermal storage	• Water tapping cycles
• Photovoltaics	• External weather data

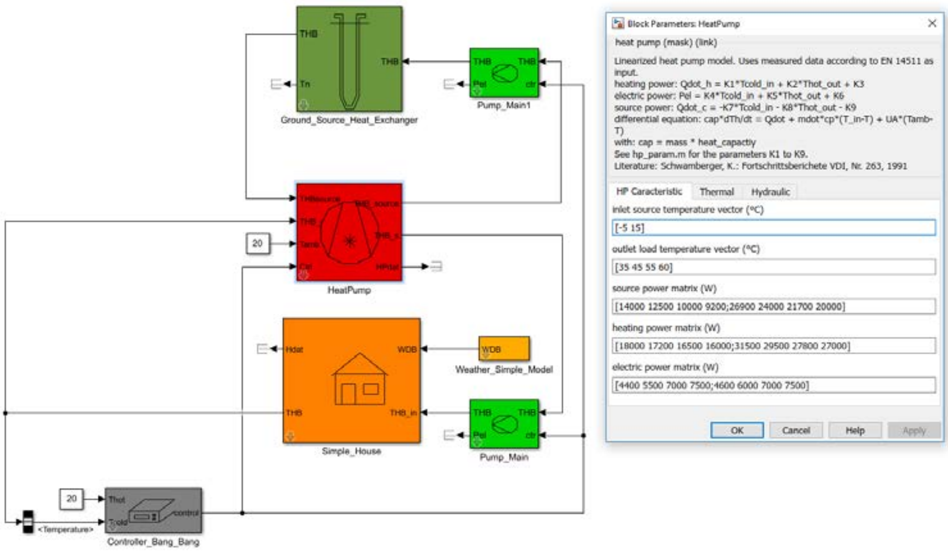


Figure 6. Example of a simple CARNOT model with parameter mask for the heat pump

1.2.7 Roof Installations

On the roof of the laboratory, six mounting points for photovoltaic or solar-thermal modules are installed. These can be manually tilted and rotated.

1.2.8 Test Components

Listed below are the components currently installed in the laboratory for performance evaluation. They were selected to be representative of components installed in typical single-family houses and work together as a well-balanced unit.

Component	Manufacturer	Model	Spec	Unit	Value
Brine/water heat pump	Viessmann	Vitocal 300-G	Power	kW	8.4
Air/water heat pump	Viessmann	Vitocal 200-S	Power	kW	4.75
DHW storage	Viessmann	Vitocell V100 CVW	Volume	L	390
DHW storage	Viessmann	Vitocell 100-B CVB	Volume	L	500
Solar-thermal collector (3x)	Energie Solaire	Absorber AS/TS 1/TSS	Surface	m^2	1.78
Photovoltaic panel (4x)	Panasonic	12 HIT-N240	Power	kW_p	2.9
Inverter	SMA	STP 5000TL-20	Power	kW	3
Battery	LG	Resu 6.5	Capacity	kWh	5.9

1.3 Examples of Previous Studies

1.3.1 Study 1: SOFOWA

The SOFOWA study has explored the potential of combining solar-thermal collectors (ST), water-based phase-change storage (PCS), photovoltaics (PV), combined photovoltaic-thermal panels (PVT) and heat pumps (HP) for space and domestic hot water heating in single-family houses. The phase-change storage in the laboratory was experimentally characterized in order to build a numerical model in CARNOT. The annual performance evaluations were conducted as pure simulations.

The study consists of two parts. In the first part, five systems for heat generation and storage (#1-5) were tested on the standard house model SFH45. This model has a defined space heating load (SHL) and was taken from IEA SHC Task 44 HPT Annex 38. Three systems (#1-3) included an air/water heat pump (A/W-HP) while dividing the roof area between solar-thermal collectors and photovoltaics. The system with only solar-thermal collectors on the roof (#1) had a much larger space heating storage (SHS), which also included domestic hot water (DHW). In system #4 (shown in Fig. 7), the air/water heat pump was "replaced" with phase-change storage and a brine/water heat pump (B/W-HP), while the solar-thermal part of the roof area was changed from glazed to unglazed, which is advantageous for convective heat gains at low ambient temperatures. System #5 is similar to system #4, except the roof area is no longer divided, but fully covered with combined photovoltaic-thermal panels.

Power and heat systems: Part 1								
System	ST	PV	B/W-HP	PCS	A/W-HP	SHS	SHL	SPF
1	50 m²				7.5 kW	10 m³	4.0 kW	13.2
2	8 m²	42 m²			7.5 kW	900 L	4.0 kW	4.0
3		50 m²			7.5 kW	900 L	4.0 kW	3.0
4	10 m² unglazed	40 m²	6.0 kW	10 m3			4.0 kW	4.2
5	50 m² PVT		6.0 kW	10 m3			4.0 kW	4.2
Power and heat systems: Part 2								
System	ST	PV	B/W-HP	PCS	A/W-HP	SHS	SHL	SPF
6	13 m² unglazed		8.0 kW	10 m3			7.5 kW	4.47

SPF: Seasonal Performance Factor before Storage

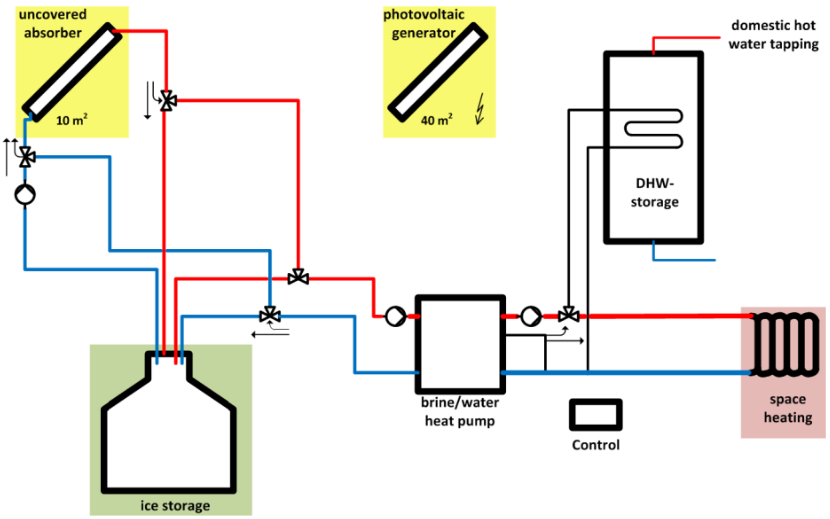


Figure 7. System #4

In Fig. 8, the annual consumption of grid electricity for systems #1, #2, #3 and #5 as well as a reference with no solar technology for SFH45 are shown. During summer, none of the tested systems had significant grid power consumption, since the photovoltaic panels in systems #2-5 supplied enough power to cover the domestic hot water production and the solar-thermal collector in system #1 has a very high SPF. During the colder part of the year, grid power consumption of systems #2 and #3 is almost identical, although the mixed system #2 has a higher SPF than the purely photovoltaic system #3. This can be attributed to the superior SPF of solar-thermal collectors compared to air-water heat pumps (compare system #1). System #1 has similar grid power consumption as systems #2 and #3 during winter, but stretches the phase of almost no grid power consumption much further into the seasonal transition. This is owed to the large collector area in spring and to the large space heating storage in autumn. The grid power consumption of system #5 is similar to systems #2-3 in shape, but lower since under cold conditions, the combination of phase-change storage and a brine/water heat pump has a higher SPF than an ambient air/water heat pump. The performance of the combined photovoltaic-thermal panels in system #5 is comparable to that of the split configuration in system #4. However, system #5 feeds more electric power into the grid.

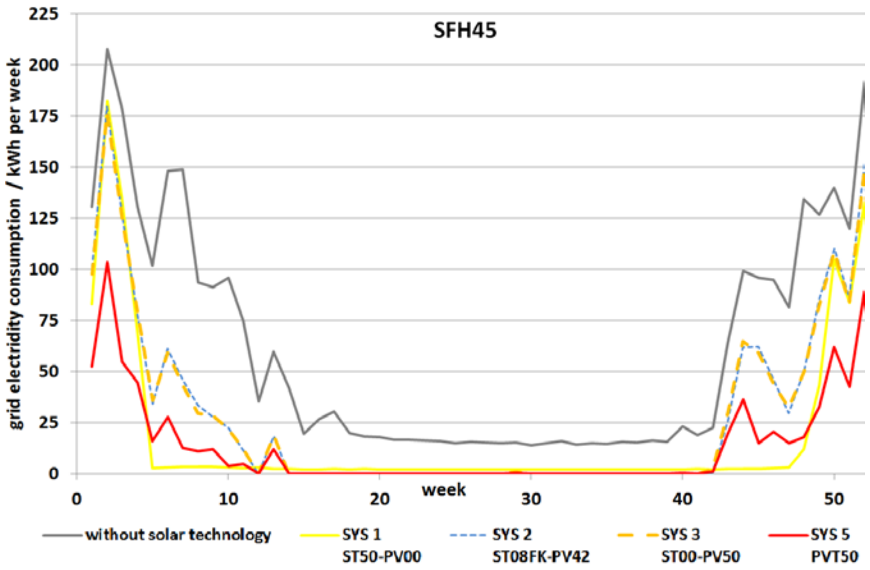


Figure 8. Annual grid electricity consumption of the systems for SFH45

In the second part, system #6 was tested on the modified house model SFH45*, which has a bigger space heating load than SFH45. Fig. 9 shows the monthly energy balance of the phase-change storage. This includes freezing and melting of the storage fluid, gains from the solar-thermal collectors, gains and losses from the ground surrounding the storage and the energy delivered to the brine/water heat pump. Two points may be highlighted here: First, the solar gains are almost completely out of sync with the heating demand and much of the gains in summer appear to be lost to the ground. Second, the thermal gains from the ground are the most significant energy source during winter.

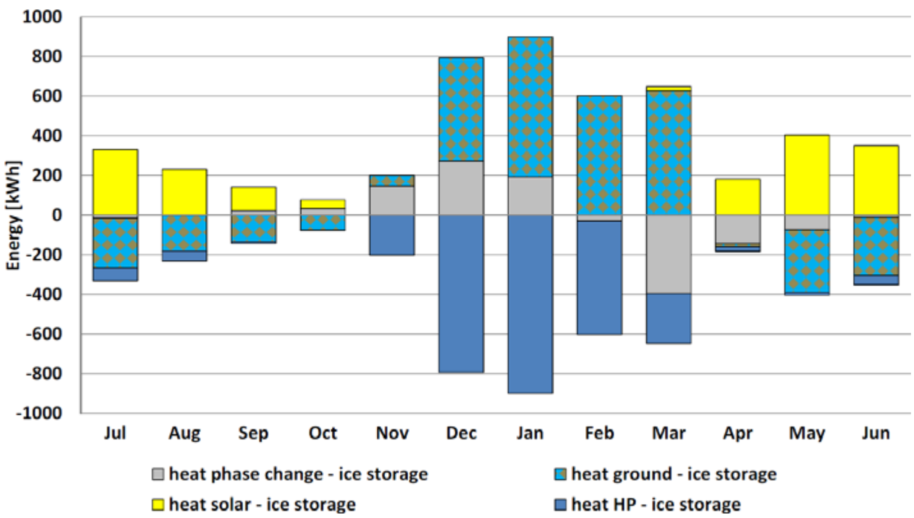
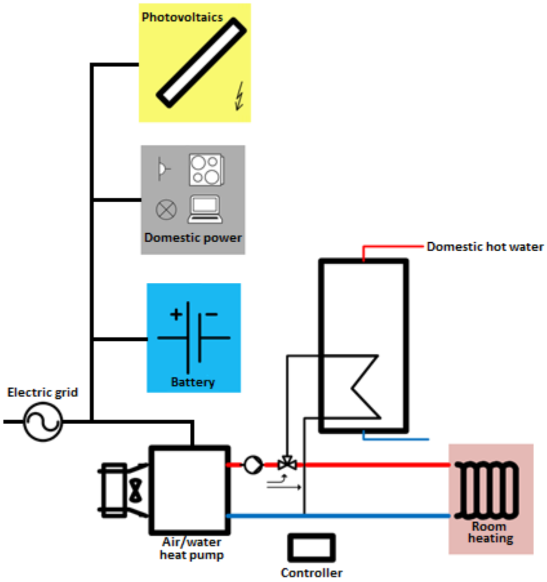


Figure 9. Monthly energy balance of the PCS for SFH45*

In conclusion, it has been shown that the systems proposed in this project can reach an annual SPF of 4.0 and higher. In comparison, this is almost as good as a ground source heat pump with conventional drilling (SPF -4.5) and much better than an air source heat pump (SPF ~3). A particular finding of this study was the dominance of convective heat gains as opposed to solar radiation gains in unglazed solar-thermal collectors, when operated below ambient temperatures with a heat pump. The energy sources in descending order of importance are convective gains on the collector, ground gains, phase change gains and radiation gains on the collector.

1.3.2 Study 2: LEWASEF (in prog.)



A subtask of LEWASEF (successor study of SOFOWA) is the evaluation of the performance of air/water heat pumps in combination with photovoltaics and a battery. Compared to phase-change storage, a battery is commonly much more restricted in capacity. Therefore, a particular focus of this study is on a learning controller, which shifts the load cycles of the heat pump to time slots with photovoltaic overproduction.

A CARNOT model of the system has been built for preliminary testing and to ensure the selected components are well balanced and appropriately scaled for a single-family house. In the next stage, this model will be integrated into the laboratory setup for validation. While the actual heat pump, domestic hot water storage, battery and photovoltaic inverter will be used, the thermodynamics of the house, the weather and the domestic electric power consumption will be provided by the simulation and implemented using the thermodynamic core and the electric emulators. The desired result of the study is a validated system for affordable and effective power and heat generation in single-family houses.

1.4 Maintenance and Collaborations

The laboratory was designed in cooperation with the university's school of architecture and is operated by the Institute for Energy in Building FHNW. The main collaborators are the Swiss Federal Office of Energy as well as various industrial partners. It is also used in the practical education of students from various majors, such as architecture, engineering and life sciences.

1.5 Additional Information

Additional information about the laboratory and the institute can be found under:
https://www.fhnw.ch/de/die-fhnw/hochschulen/architektur-bau-geomatik/institute/iebau
(currently only available in German)

Located next to the ERL is the Lighting and Façade Lab. Placed on a rotating platform, this installation is used to test daylight, glare, artificial lighting, façade constructions and blinds.

1.6 Relevant Publications

Dott, R.; Afjei, T.; Genkinger, A.; Dailbard, A. et al. "Heat Pump Models: A Technical Report of Subtask C, Report C2, Part C" Models of Sub-Components and Validation for the IEA SHC Task 44 / HPT Annex 38 (2013)

Haller, M.Y.; Dott, R.; Ruschenburg, J.; Ochs, F. and Bony, J. "Part A: General Simulation Boundary Conditions: A Technical Report of Subtask C, Report C1, Part A" Models of Sub-Components and Validation for the IEA SHC Task 44 / HPT Annex 38 (2013)

Haller, M.Y.; Bertram, E.; Dott, R.; Afjei, T. et al. "Part A: Summary: A Technical Report of Subtask C, Report C2, Part A" Models of Sub-Components and Validation for the IEA SHC Task 44 / HPT Annex 38 (2013)

Hadorn, J.-C. “Solar and Heat Pump Systems for Residential Buildings” ISBN: 978-3-433-03040-0 (2015)

Dott, R.; Winteler, C.; Afjei, T.; Genkinger, A. “SOFOWA Final Report” Institute for Energy in Building, FHNW Muttenz (2016)

Dott R.; Haller M.Y.; Ruschenburg J.; Ochs F. and Bony J. “The Reference Framework for System Simulations of the IEA SHC Task 44 / HPT Annex 38 Part B: Buildings and Space Heat Load A technical report of subtask C Report C1 Part B”, available on http://task44.iea-shc.org, 2013