Report on Solar Combisystems Modelled in Task 26

Appendix 5:
Generic System #9b: Space Heating Store with Immersed DHW Tank and External DHW Store with Auxiliary

A Report of IEA SHC - Task 26

Solar Combisystems

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INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

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Appendix 5:
Generic System #9b: Space Heating Store with Immersed DHW Tank and External DHW Store with Auxiliary

by

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A technical report of Subtask C

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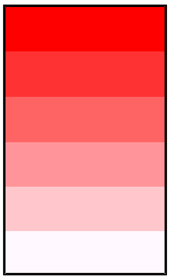
Contents

1 General description of System #9b, Space Heating Store with Immersed DHW Tank and External DHW Store with Auxiliary

Direct connection of solar loop and heat distribution to the buffer tank (NORWAY)



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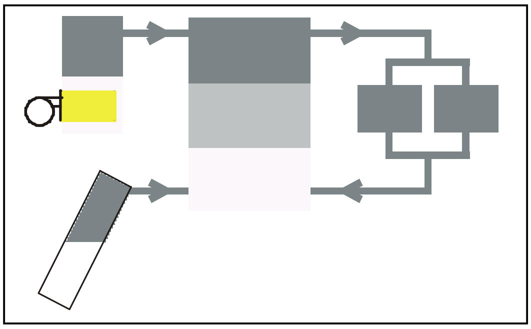


Main features

In this system, a domestic hot water tank is built in the space heating storage tank. The space heating tank size and the size of the domestic hot water tank can be independently chosen over a wide range.

The system is meant to supply residential buildings, estates of terraced houses or multiple family houses with solar energy for space heating and domestic hot water preparation. To operate the system in the best possible way, low temperature heating on the heat release side is required (floor or wall heating). Typically the houses or flats are supplied by the central storage tank on a low temperature level of approx. 30 to 40^0C (heating operation temperature). To prepare domestic hot water an immersed domestic hot water tank is mounted inside the buffer tank. If necessary the preheated domestic hot water leaving the vessel inside the buffer tank is heated up further to the required threshold temperature for the domestic hot water in a second domestic hot water tank which is located downstream, outside the buffer store (Fig. 1).

Heat management philosophy

All system functions except the DHW auxiliary heating are controlled by a single control unit.

The pump of the collector loop is controlled according to the temperature difference between the collector sensor and the sensor at the bottom of the storage tank. If the temperature at the top of the collector is higher than at the bottom of the tank and the difference reach a given limit, the pump of the collector loop is started up.

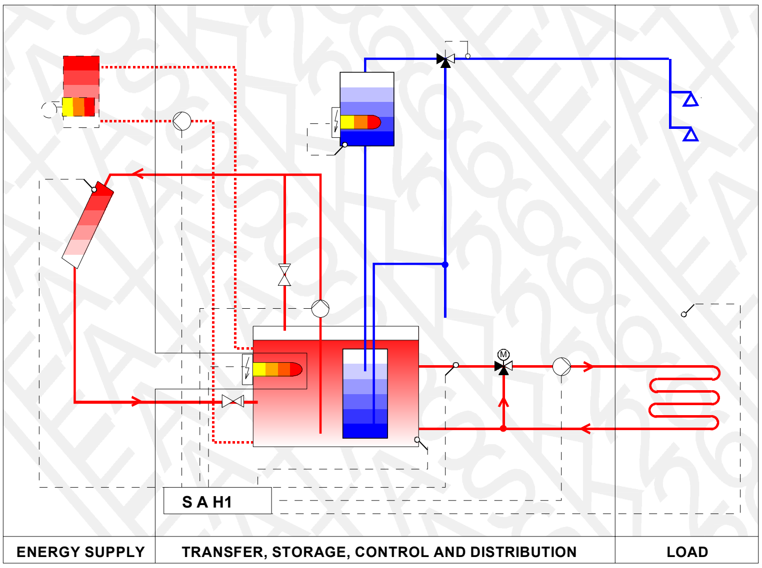


Fig. 1 Hydraulic setup of the SolarNor combisystem.

The supply of auxiliary heat for space heating is basically controlled by a thermostat. Optionally a dynamic thermostat function is provided (thermostat setting depending on the outdoor temperature). In the case of electricity as auxiliary energy source, the controller is also programmable to utilize off-peak electricity at night time.

Auxiliary heat:
If the solar yield is not high enough, different auxiliary sources might supply the needed energy to the buffer tank. Oil, gas or biomass burners are possible, in Norway for the time being mainly electricity, generated with hydro power is used. Auxiliary heating is started up depending upon the temperature state and requirements. Due to the low temperature heat distribution system in most cases a buffer temperature of 25 to 35 °C at the upper part of the tank is sufficient to supply heat to the living area. If the temperature drops below this, the auxiliary heats the upper part of the buffer to the required temperature for the flow into the heat distribution system, see Fig. 1. For usual combisystem with a total buffer volume of 1000 to 4000 litres the immersed DHW tank inside the buffer (tank in tank) has a capacity of 200 litres.

Space heating:
The heat transport to the space heating loop is controlled by an “on/off” operation of the floor- or wall heating circulation pump and/or thermostat valves at the manifold of the distribution pipes. The control parameters are the outdoor temperature, the solar irradiance (through the windows) and optionally the wind speed (in coastal regions).

Preparation of DHW:
As the volume of the buffer tank the required volume of the domestic hot water store, which is located downstream outside the buffer tank, has to be adapted according to the specific demands of the user. For residential buildings a tank of 80 up to 150 litres in accordance to the consumption and the user specified comfort is sufficient.
The auxiliary heater for this domestic hot water store is controlled by a separate thermostat. If necessary the pre-heated domestic hot water coming from the main store is heated further up to the threshold temperature, chosen by the user. As for the buffer tank different auxiliary sources are possible. In Norway again hydro power electricity is common.

Specific aspects
Pure water is used as the common heat transfer fluid in the solar collector loop, the space heating tank and the heat distribution system. Overheating and freeze protection are provided by the drainback principle. All circuits are connected to the central buffer store without any intermediate heat exchanger. Accordingly, all components are made of stainless steel, copper or plastics. The space heating tank operates at atmospheric pressure. The DHW tank located inside the space heating tank is operated at the usual domestic water pressure.

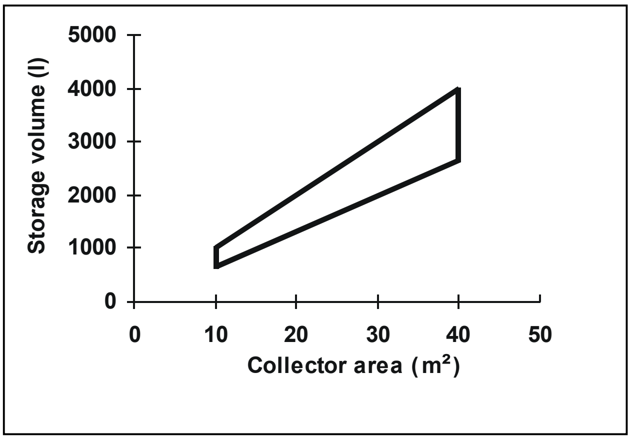


Fig. 2 Application range of combisystem #9b.

A special polymer flat-plate absorber is used, see Fig. 3. The particular design of the absorber plate helps to stabilize the water level in the space heating tank, independently from the status of the collector loop pump (operation or standstill).

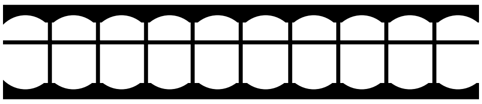


Fig. 3 Principle of the cross-section of the polymer absorber. Water fills the upper, smaller channels.

Influence of the auxiliary energy source on system and tank design

Developed in Norway under the circumstances of environmental friendly and cheap electricity generated with hydro power, the implementation of auxiliary heat is quite simple. Both, in the buffer tank and in the separately located DHW tank immersed electric heating elements are installed. The heating power can be chosen in a wide range. Typically elements with 3, 6 or 12 kW per element are used. Depending on the size of the buffer tank and the domestic hot water demand in total usually 6 or 12 kW per storage are installed. In respect to other auxiliary sources like biomass (wood logs, woodchips or pellets), oil, gas or district heating the buffer and DHW tank might be equipped with immersed heat exchangers. Depending on the boiler a direct coupling to the central buffer tank might be possible. Regarding the storage design an immersed gas, oil or pellets burner located inside the tank is challenging and might be available in the future. In combination with biomass the large storage volume is a particular advantage.

Cost (range)

The total cost of the whole system in Norway is about 11 000 EUR, with a 20 m^2 collector, a 2 000 litre storage tank, a gas or oil burner and a heating floor. Installation costs are included in these figures. A similar reference system without solar heating costs about 8 000 EUR.

Market distribution

This system was launched on the Norwegian market in 1997. About 4 000 m^2 of collectors have been installed. Manufacturer: SolarNor AS

solarnor

Fig. 4 Company logo of Solarnor AS, Norway.

2 Modelling of the system

2.1 *TRNSYS model*

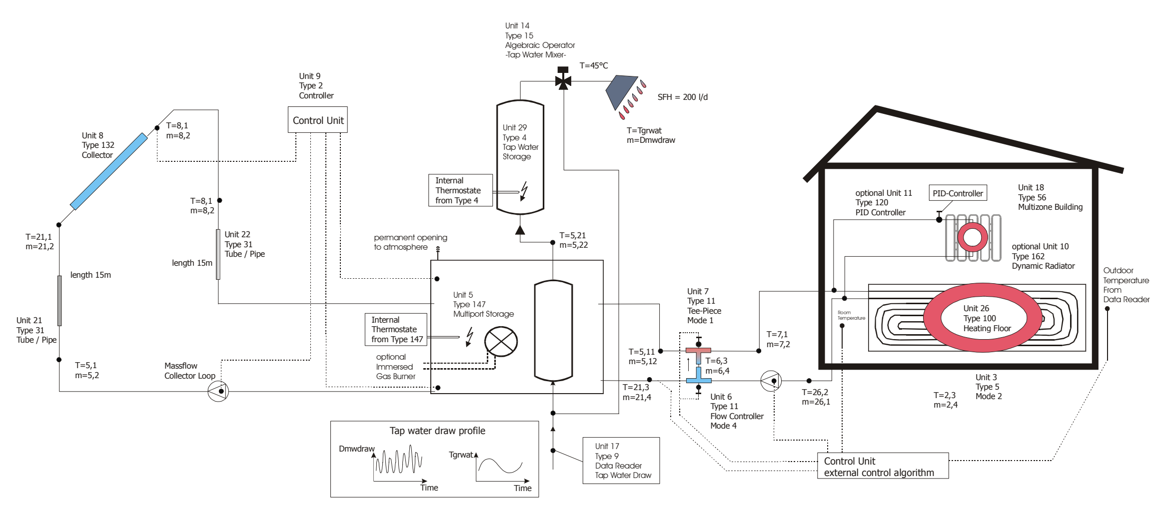


Fig. 5 Modelling of System #9b within TRNSYS.

2.2 *Definition of the components included in the system and standard inputs data*

2.2.1 Collector

Type : 132	Version Number : 1.03	
Collector	η0, a1, a2, inc. angle modifier (50°)	0.8, 3.5, 0.015, 0.9
	Area	0 - 30 m²
	Specific mass flow	50 l/m²h

Data defined in [2].

2.2.2 Pipes between Collector and Storage

Model :	TRNSYS Type 31 One pipe between collector and heat store (flow), one pipe between heat store and collector (return).	Length: 15 m each
Pipes :	Inner diameter: 25.6 m	Total Length : 30 m
Insulation :	Thickness : 28 mm	Thermal Conductivity : λ= 0.04 W/(mK)

2.2.3 Storage

2.2.3.1 Main Buffer Tank

Type : 147 Version Number : 1.21

Storage tank	Total volume	1000 - 4000 dm³
	Height excl. insulation	1.25 m (for all volumes)
	Store volume for auxiliary	approx. 35% of total volume
	Number of nodes for Type 147	100
	Storing Medium	water
	Insulation thickness, thermal conductivity	15-20 cm, λ= 0.04 W/(mK)
	Auxiliary, electric heating element	12 kW
	Heat input system collector	direct charging (water)
	Position of sensor, collector loop	5 cm from bottom
	Start/Stop $\Delta\vartheta$ temp. Coll. loop, (hyst.)	7 K, 4 K (3 K)

Unpressurized rectangular stainless steel tank with permanent opening to the atmosphere. No immersed heat exchangers. Direct charging from collector loop, direct discharging by the heat distribution system, medium water. Immersed, pressurized domestic hot water tank ("tank in tank").

Immersed electric heating element or gas burner for auxiliary heating in the upper part of the tank. Variable threshold-temperature according to the space heat demand. External domestic hot water afterheater, downstream the immersed domestic hot water tank.

2.2.3.2 External Domestic Hot Water Tank

Type : 4 Version Number : 3/93

Storage tank	Total volume	80 dm³
	Height excl. insulation	0.64 m
	Store volume for auxiliary	total volume
	Number of nodes for Type 4	15
	Storing Medium	water
	Insulation thickness, thermal conductivity	5 cm, λ= 0.04 W/(mK)
	Auxiliary, electric heating element	12 kW
	Position of electric heating element	At the bottom
	Start/Stop $\Delta\vartheta$ temp. Auxiliary (hyst.)	on=45°C; off= 47,5°C (2,5 K)

Pressurized stainless steel tank with immersed electric heating element at the bottom. Tank located downstream of the main buffer tank.

Set-temperature of domestic hot water adjusted according to the demand given in the reference conditions.

2.2.4 Electric Heating Elements

Main buffer tank		50 kW
Type 147		0 kW
	Efficiency [1]	
	Dynamic thermostat, $\Delta\vartheta$, hysteresis	different control parameters
		dep. on location and building
Domestic hot water tank	Heating capacity max. (SFH)	50 kW
Type 4		0 kW
	Efficiency [1]	
	Dynamic thermostat, $\Delta\vartheta$, hysteresis	on=45°C; off= 47,5°C (2,5 K)

[1] Note that an overall efficiency factor of 0.9 for all electricity used for auxiliary heating is implemented within the evaluation of the simulation results, see chapter 4 and 5.

Due to the fact that the predominant number of systems are mounted in Norway, for auxiliary purpose electrical heating elements are implemented within the simulations. Both, for the main buffer tank and for the 80 l domestic hot water tank immersed electric heating elements as specified in chapter 2.2.4 are implemented.

2.2.5 Boiler

Type 147 – Multiport Storage, Storage Model with integrated gas boiler

Condensing		50 kW
Boiler		0 kW
	Mean efficiency	85 %
	Minimum running time	no limitation
	Minimum stand still time	no limitation
	Dynamic thermostat, $\Delta\vartheta$, hysteresis	different control parameters

In respect to further development of the system and concerning the possibilities to calculate different auxiliary heaters, the specified gas burner was implemented. Different types of gas might be chosen, condensing effects of water within the exhaust are taken into account. Due to the actual mounting conditions of the system which mainly took place in Norway, all calculations concerning this task are carried out with electric heating elements as auxiliary.

2.2.6 Building

Type56 Data of the building defined in [3]

The calculations are carried out for single-family houses with different insulations standards. To take the wide range of different climates all over Europe into consideration, the buildings are virtually located at three different places. Stockholm in Sweden, Zürich in Switzerland and Carpentras in France. Concerning the thermal insulation for each location three different buildings with an total annual space heating demand of 30, 60 or 100 kWh/(m²a) had been defined. Each building has a living area of 140 m². They were calculated with solar combisystems that differs in collector size and store volume. For heat distribution all buildings were equipped with a floor heating system.

2.2.7 Heat distribution

Heating Floor – Radiators

Heating Floor	Thickness built of two materials	
	Area	140 m²
	Specific heat of floor material (both materials)	0.92 kJ/(kg·K)
	Heat conductivity coefficient of floor material	1.75 / 0.03 W/(m·K)
	Density of floor material	
	Space between the pipes	20 cm
Radiator	Radiator area (SFH)	Not used
	Heat capacity (SFH)	-
	Set flow- and return temperatures (SFH)	-
	Set flow rate	-

(Data defined in [2]).

2.2.8 Domestic hot water demand

To take the domestic hot water demand for the given single-family houses into account, a load file containing the massflow of domestic hot water in timesteps of 6 minutes was used. For further information regarding the domestic hot water draw off profile see [2]. The temperature of the entering fresh (cold) water was calculated for the different locations dependent on the time of the year. Details are also given in [2].

Note:

For all simulations (space heating loads and locations) the same domestic hot water load file was used.

2.2.9 Control strategy

Floor heating

The floor heating is controlled depending on the outdoor and the indoor temperature. For the different locations and the different insulation standards of the buildings the design temperature of the heating floor (T-heating floor, max) and some control parameters of the algorithm has to be adapted. The design temperature varies in a range from 30 to 40 °C. To define a response function for the flow temperature into the heating floor according to the outdoor and indoor temperature a second, theoretical minimum temperature of the flow has to be specified. For fast changing of the outdoor-temperature a variable response factor for amplification is integrated.

The control algorithm is implemented within the simulations using Type 15, Algebraic Operations and the Equation Statements.

Controller : Type 2
Functions : Collector Controller
Udb=7 K Ldb=4 K
Hysteresis = 3 K

Electric heating elements
Functions : Integrated in Type 147 and Type 4
Auxiliary for space heating (Type 147)
Auxiliary for domestic hot water (Type 4)
For control algorithms and adjustable values
see description in chapter 2.2.3 and 2.2.4.

Controller : Type 120
Functions : optional, for calculations with radiator system,
not used for the calculations within this task
Controller / Radiator (default values)

Width of PID-band	± 3 K
Proportional gain	0.8
Integral gain	0.05
Differential gain	0.0

2.3 Peculiarities using floor heating for heat distribution

The SolarNor system is preferably combined with a floor or wall heating system, distributing energy for space heating within the building. Due to this the calculations had been carried out using the introduced heating floor (see section 2.2.7). For all simulations the heating floor, Type 100 was used. In general the use of floor heating instead of radiators, which had been implemented in the reference system, lead to significant less overheating penalties compared to the reference system. Table 1 show the overheating penalties calculated for the reference building **with** a floor heating system as described above. For the calculations the space heating was switched off. The significant reduction of overheating penalties can be explained by inertial effects of the heating floor, which definitely reduce overheat hours during summer.

To make System #9b including floor heating comparable to the other solar combisystems within the task, for evaluation of the system performance the new calculated penalty values were taken. The penalty functions are defined in [2]

Heating Floor Building Pen Up: **used for all calculations of systen #9, SolarNor**

		Zurich			Carpentras			Stockholm	
	SFH 30	**SFH 60**	**SFH 100**	**SFH 30**	**SFH 60**	**SFH 100**	**SFH 30**	**SFH 60**	**SFH 100**
JAN	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
FEB	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MAR	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
APR	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MAY	0,96	0,00	0,00	272,90	319,20	201,80	40,87	19,54	0,69
JUN	95,20	31,74	0,00	1413,00	2023,00	1710,00	340,60	295,80	64,30
JUL	978,10	1346,00	1109,00	3889,00	6692,00	7870,00	739,60	899,90	546,40
AUG	1013,00	1394,00	1008,00	3026,00	5038,00	5378,00	751,30	951,10	656,20
SEP	84,41	39,61	0,00	1975,00	3155,00	3134,00	0,28	0,00	0,00
OCT	0,00	0,00	0,00	98,18	48,98	8,82	0,06	0,00	0,00
NOV	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
DEC	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
SUM	**2172**	**2811**	**2117**	**10670**	**17280**	**18300**	**1873**	**2166**	**1268**

Reference Bulding Pen Up: **recalculated for the reference system**

		Zurich			Carpentras			Stockholm	
	SFH 30	**SFH 60**	**SFH 100**	**SFH 30**	**SFH 60**	**SFH 100**	**SFH 30**	**SFH 60**	**SFH 100**
JAN	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
FEB	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MAR	0,02	0,00	0,00	2,04	0,00	0,00	0,00	0,00	0,00
APR	0,01	0,00	0,00	0,00	0,00	0,00	5,98	0,00	0,00
MAY	25,59	2,40	0,00	855,50	801,20	538,60	263,60	145,00	33,10
JUN	654,00	237,50	4,92	3931,00	4075,00	2937,00	1344,00	878,80	200,20
JUL	2886,00	2837,00	1957,00	9398,00	11860,00	11730,00	2357,00	2068,00	1071,00
AUG	3078,00	3006,00	1861,00	7649,00	9226,00	8243,00	2333,00	2083,00	1205,00
SEP	544,60	221,80	6,52	5203,00	5928,00	4912,00	12,53	4,99	0,32
OCT	0,00	0,00	0,00	511,60	202,30	34,51	17,90	4,36	0,00
NOV	0,00	0,00	0,00	3,81	0,00	0,00	0,00	0,00	0,00
DEC	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
SUM	**7188**	**6304**	**3829**	**27550**	**32090**	**28390**	**6334**	**5184**	**2509**
Reference Milestone Report	**7101**	**6208**	**3766**	**27338**	**31807**	**28129**	**6247**	**5091**	**2453**
delta recalculation	**1,23%**	**1,55%**	**1,67%**	**0,78%**	**0,89%**	**0,93%**	**1,39%**	**1,83%**	**2,28%**

Reference Bulding Pen Low: **recalculated for the reference system**

		Zurich			Carpentras			Stockholm	
	SFH 30	**SFH 60**	**SFH 100**	**SFH 30**	**SFH 60**	**SFH 100**	**SFH 30**	**SFH 60**	**SFH 100**
JAN			0,0218						0,0000
FEB			0,0000						0,0000
MAR			0,0913						0,0000
APR			0,0000						0,0000
MAY			0,0000						0,0000
JUN			0,0000						0,0000
JUL			0,0000						0,0000
AUG			0,0000						0,0000
SEP			0,0000						0,0000
OCT			0,0000						0,0000
NOV			0,0000						1,9480
DEC			0,2906						0,0000
SUM			**0,4036**						**1,9480**
Reference Milestone Report			**0,4000**						**2,0000**

Table 1 Differences between penalty values for the reference building with/without floor heating (in addition see recalculation of reference values).

2.4 Validation of the system model

For simulations the system model has been validated in several ways.

1. For all calculations of System #9b the heat distribution for the space heating is realized by using floor heating, Type 100, heating floor instead of radiators. Due to the different inertia caused by the properties of the floor material of the heating floor compared to the floor in the reference building, new penalty values has to been calculated. In the opposite to this all systems with radiators are calculated with the properties of the reference building. The new penalty values have been compared to those for System #3, which is the only system beside #9b using a heating floor. Hence the new penalty values are validated against System #3.

2. The system was calculated with and without space heating load as well as with and without domestic hot water preparation. The effects were studied in detail and if possible compared to references. The calculations were carried out in all possible combinations of locations and building standards. For every location and the different insulation standards the courses of all important temperatures for at least one system design were examined during the simulation by means of a graphic online.

3. A large number of calculations for different climates and building types had been carried out. The results had been compared with each other within the systems. All results, including the new penalty values had been checked against the results of other systems (e.g. System #3), as well as overall plausibility. Last but not least the values have been checked according to their plausibility in respect to practical and theoretical experience.

3 Simulations for testing the library and the accuracy

3.1 Result of the TRNLIB.DLL check

The following figure show a comparison of the results for the SCS1a.trd file, dated Feb. 2001 with those from a trnlib32.dll compiled as a basis for the system simulations of the SolarNor system. Mainly the types and corresponding versions given in the table "sheet-types-task26.xls" had been used. One exception is, that Type 170, actual version 3.0 dated 06/Nov/2000 was linked. Note, that burner type 170 is not used within the simulations of System #9b. The second exception is collector model Type 132, where version 1.03 dated 13/Nov/2000 was used.

	$F_{sav,therm}$	$F_{sav,ext}$	F_{SI}	E_{boiler}	$Q_{penalty,SHLow}$	$Q_{penalty,SHUp}$	$Q_{penalty,DHW}$
reference results	0.7900	0.7406	0.3006	9443	30.0	26480	no
results of trnlib.dll used for simulations	0.7898	0.7403	0.2977	9452	30.11	26610	no
Difference (rel.)	+ 0.025 %	+ 0.041 %	+ 0.96 %	+ 0.095 %	+ 0.37 %	+ 0.49 %	-

Table 2 Results of trnlib32.dll check, calculations without special types for System #9b.

In fact of the floor heating and the special system design of the SolarNor combisystem, to make simulations possible the following modifications and additional component models had to be implemented within the trnlib32.dll:

- Burner, Type 170, version 3.0 dated 06/Nov/2000
  (Burner type 170 is not used within the simulations of System #9.)
- Collector, Type 132, version 1.03 dated 13/Nov/2000
- Radiation processor, Type 16, version 5/01 date of file 15/Jun/2002
- Multiport storage, Type 140, Ver. 1.99C HD dated 15/March/2001 (w/o subroutines)
- Multiport storage, Type 147, Ver. 1.21 HD dated 08/Nov/2000
  (the integrated burner in Type 147 was not used)
- Heating Floor Model, Type 100, Ver. 1.3 dated 08/March/00

Including all the modifications listed above a new calculation to reproduce the reference data was carried out. Table 3 shows the corresponding values. Because this set of types amount the best fit regarding the new overheating penalty values compared to the French System #3, which also had been calculated with a floor heating system, to make comparison possible it was agreed on to use this type configuration for all system simulation of System #9b, even in comparison with the reference it is slightly worse.

	$F_{sav,therm}$	$F_{sav,ext}$	F_{SI}	E_{boiler}	$Q_{penalty,SHLow}$	$Q_{penalty,SHUp}$	$Q_{penalty,DHW}$
Reference results	0.7900	0.7406	0.3006	9443	30.0	26480	no
Results of trnlib.dll used for simulations	0.7996	0.7498	0.3065	9009	28.78	26640	no
Difference (rel.)	+ 1.012 %	+ 1.012 %	+ 1.02 %	- 4.6 %	- 4.1 %	+ 0.6 %	-

Table 3 Results of trnlib32.dll check. This trnlib32.dll was used to simulate the SolarNor system and to calculate the penalty values for the building with floor heating.

3.2 Results of the accuracy and the timestep check

The results of the accuracy check to determine the convergence and integration error tolerances as well as the suitable timestep for the simulations are listed in Table 4.
The target was to reduce the epsilon ε from one parameter set to the next, and to reduce the difference below 0.01.

Where

$$\varepsilon = \frac{F_{save,herm}(i) - F_{save,therm}(i-1)}{F_{save,therm}(i-1)} * 100\%$$

with

$$f_{\mathrm{sav,therm}} = 1 - \frac{\frac{Q_{\mathrm{boiler}}}{\eta_{\mathrm{boiler}}} + \frac{Q_{\mathrm{el.heater}}}{\eta_{\mathrm{el.heater}}}}{\frac{Q_{\mathrm{boiler,ref}}}{\eta_{\mathrm{boiler,ref}}}} = 1 - \frac{E_{\mathrm{aux}}}{E_{\mathrm{ref}}}$$

The procedure for choosing a set of convergence and integration tolerances and a suitable timestep was as follows:

1. Simulation of the base case of System #9b for the tightest tolerance (0.0001) and shortest timestep (1/60). All component values within the TRNSYS-dek must have reasonable values.
   This tolerances and timestep set is defined as the reference simulation.
2. Variation of convergence and integration tolerances, variation of timestep.
3. Choose of a final set of values with respect to the epsilon ε, calculation time and stability regarding modifications within the TRNSYS-dek.

As shown in Table 4 on the next page smaller error tolerances as well as smaller timesteps compared to the chosen set of values have nearly no influence according to the accuracy specification for the simulations. The values also correspond with experience gained from a large number of comparable system simulations carried out with TRNSYS.

All together there was no significant difference in the wide range were the convergence, the integration error tolerances and the timestep had been varied.

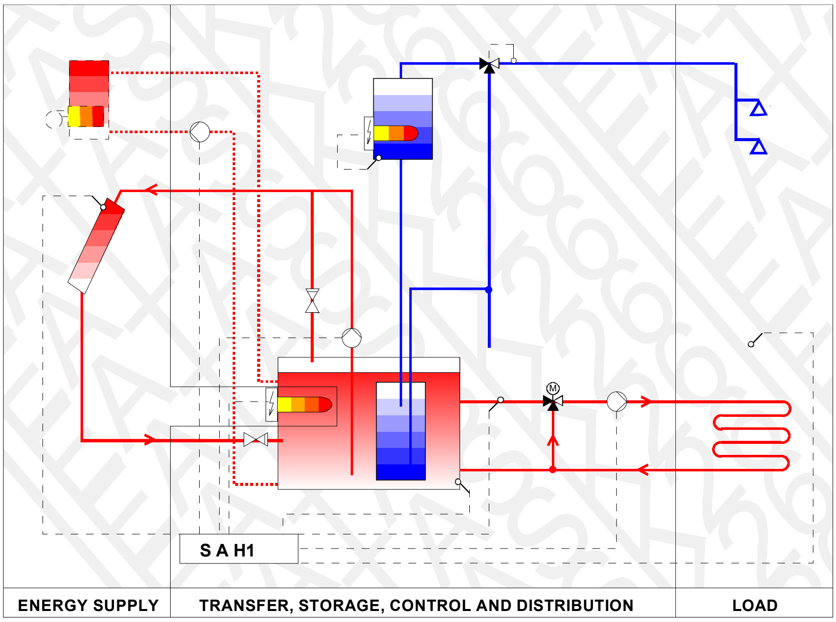
Conv tolerance	Int tolerance	Timestep	$F_{sav,therm}$	Epsilon
0.1	0.1	1/20	0.3216	
0.01	0.01	1/20	0.3190	– 0.0081
0.001	0.001	1/20	0.3205	+ 0.0047
0.0001	0.0001	1/20	0.3210	+ 0.0016
0.001	0.001	1/20	0.3205	
0.001	**0.001**	**1/40**	**0.3232**	**+ 0.0084**
0.001	0.001	1/20	0.3205	
0.001	0.001	1/60	0.3242	+ 0.0120
0.01	0.01	1/20	0.3190	
0.001	0.001	1/60	0.3242	+ 0.0163
0.001	0.001	1/40	0.3232	
0.001	0.001	1/60	0.3242	+ 0.0031
0.0001	0.0001	1/40	0.3233	
0.0001	0.0001	1/60	0.3241	+ 0.0025
0.001	0.001	1/40	0.3232	
0.0001	0.0001	1/40	0.3233	+ 0.0003
0.001	0.001	1/60	0.3242	
0.0001	0.0001	1/60	0.3241	– 0.0003

Table 4 Determination of the relative convergence and integration error tolerances. Determination of the simulation timestep.

A good compromise between simulation time and accuracy was found with the values shown in the bold frame. For all simulations within the calculations for the presented system the convergence error tolerance was chosen to 0.001 (0,1%). Equal to this the integration error tolerance was chosen to 0.001 (0,1%). For the simulation timestep 1/40 of an hour, which corresponds to 1.5 minutes is suitable.

4 Sensitivity Analysis and Optimisation

4.1 Presentation of results



System #9b
Low temperature heat distribution system, no heat exchangers. Domestic hot water preheating, external domestic hot water tank. Drainback collector loop, pure water in all circuits, athmospheric pressure. Different auxiliary sources.

Main parameters (Base Case, *BC*):			
Building:	*SFH 60*	Storage Volume:	*1.5 m^3*
Climate:	*Zurich*	Storage height: (without insulation)	*1.25 m*
Collectors area:	*20 m^2*	Heat Exchanger:	*no heat exch.*
Collector type:	*Standard Flat Plate*	Position of in/outlets:	*typical*
Specific flow rate: (Collector)	*50 kg/m^2-h*	Thermal insulation buffer:	*15/20 cm* λ= 0.04 W/(mK)
Collector azimuth/tilt angle:	*0 / 45°*	Thermal insulation ext. domestic hot water tank	*5 cm* λ= 0.04 W/(mK)
Collector controller upper/lower dead band:	*7 / 4 °K*	Nominal auxiliary heating rate, buffer:	*12 kW*
space heating	*depending on out-/indoor temperature*	Nominal auxiliary heating rate, external domestic hot water tank:	*12 kW*
Simulation parameter:		Storage nodes buffer :	*100*
Convergence Tolerances (rel.)	*0.,001*	Storage nodes domestic hot water tank:	*15*
Integration Tolerances (rel.)	*0.001*	Timestep:	*1/40 h (1.5 min.)*

Table 5 Main parameters for the base case, System #9b.

To investigate the sensitivity of the system in respect to variations of different parameters a large number of TRNSYS simulations had been carried out. The goal was to show the influence of the main system parameters (key-parameters) as collector area and storage volume in combination with different insulation standards and locations of single-family houses. Beside a number of special investigations on details of the calculations were carried out according to the following diagram:

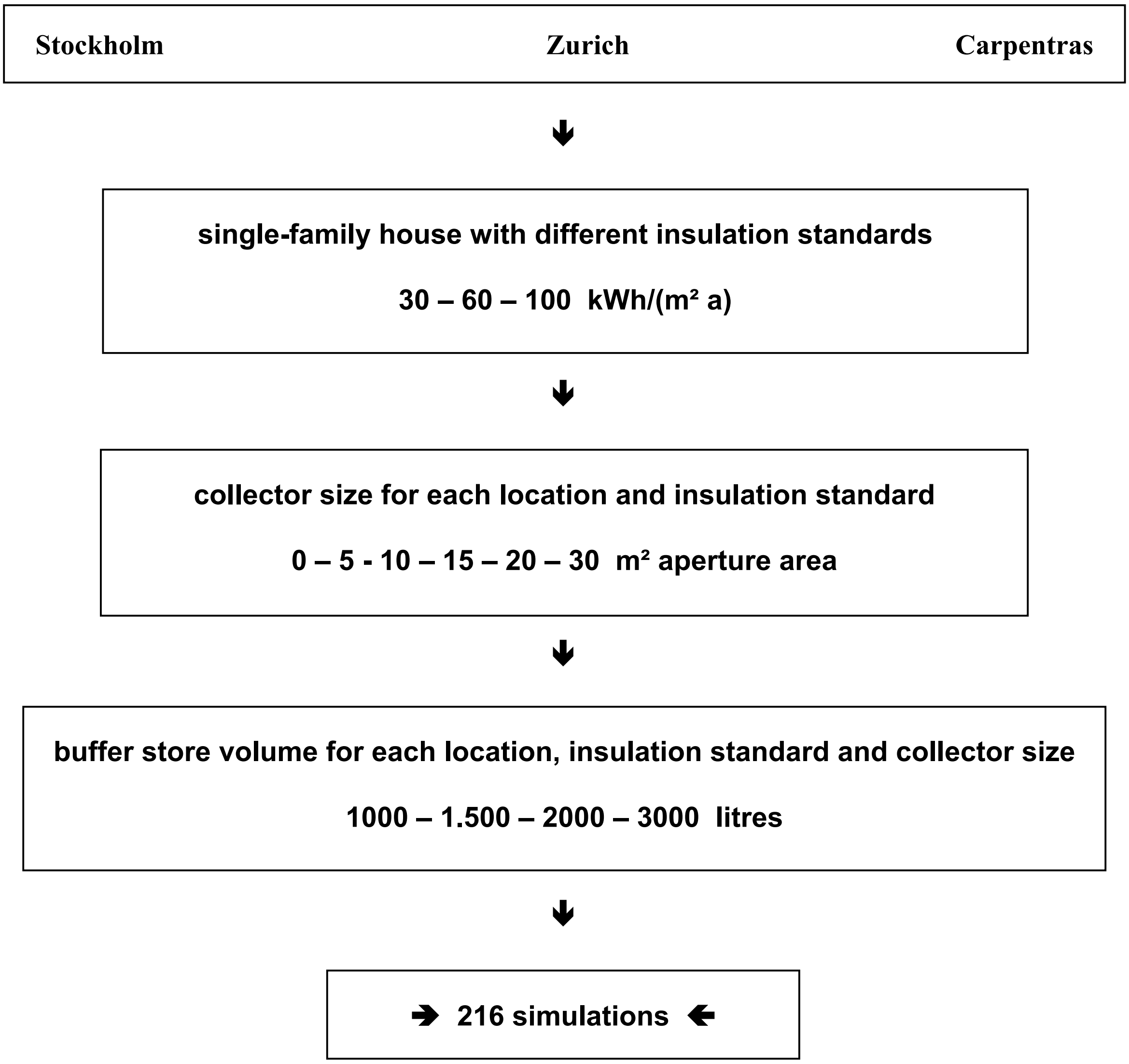


Fig. 6 Matrix for TRNSYS simulations, System #9b, SolarNor.

Fig. 7 shows the application range of the system as described in chapter 1 and the position of the **base case.** The range of the simulations as described in Fig. 6 is marked with the grey area.

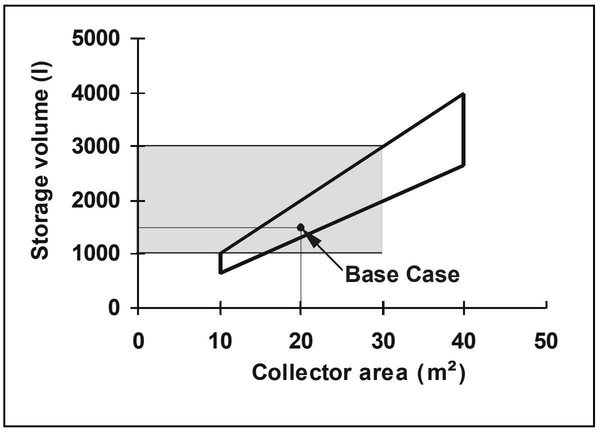


Fig. 7 Application range of System #9b.

Summary of Sensitivity Parameters			
Parameter	Variation	[1] Variation in $f_{sav,ext}$	Figure
Base Case (BC) Singel Family House, Zurich 60 kWh/(m²a) (collector size: 20 m², store size: 1.5 m³)	–	28.45 %	diff. figures
Collector size [m²] (fixed store size (1.0 m³)	5 – 30	14.12 – 30.88 %	Fig. 12
Collector size [m²] (fixed store size (1.5 m³)	5 – 30	14.43 – 33.23%	Fig. 9
Collector size [m²] (fixed store size (2.0 m³)	5 – 30	14.80 – 34.93%	Fig. 13
Collector size [m²] (fixed store size (3.0 m³)	5 – 30	14.82 – 36.92%	Fig. 14
Heat demand [kWh/(m² a)] (Zurich: collector size: 20 m², store size: 1.5 m³)	30 – 100	18.19 – 39.04	Fig. 11
Store Size [m³] (Zurich: 30 kWh/(m² a), collector size: 20 m²)	1.0 – 3.0	37.16 – 41.70%	Fig. 15
Store Size [m³] (Zurich: 60 kWh/(m² a), collector size: 20 m²)	1.0 – 3.0	26.87 – 30.92%	Fig. 16
Store Size [m³] (Zurich: 100 kWh/(m² a), collector size: 20 m²)	1.0 – 3.0	16.91 – 20.12%	Fig. 17
a) Specific Store Size [dm³/m²] b) Collector Size [m²] (Stockholm Single-family House, 60 kWh/(m² a))	a) 30 – 300 b) 10 – 30	18.85 – 32.51%	Fig. 19
a) Specific Store Size [dm³/m²] b) Collector Size [m²] (Zurich Single-family House, 60 kWh/(m² a))	a) 30 – 300 b) 10 – 30	24.80 – 43.17%	Fig. 20
a) Specific Store Size [dm³/m²] b) Collector Size [m²] (Carpentras Single-family House, 60 kWh/(m² a))	a) 30 – 300 b) 10 – 30	54.59 – 81.81%	Fig. 21
Climate (SFH 60 kWh/(m²a), coll. size: 20 m², store: 1.5 m³)	Stock. / Zur. / Carp.	22.4% / 28.4% / 56.9%	Fig. 23

Table 6 Summary of sensitivity parameters.

[1] The variations if fractional savings (extended) indicated in the table does not represent the values for the extremes of the range, rather the minimum and maximum values for the range indicated.

4.2 Basic elements and fundamentals for simulations/calculations

The general settings of the thermostats, both for the central buffer store and also for the external domestic hot water store, downstream the buffer had not been changed within the simulations. Independent of this the set temperature and some parameters of the controller for the buffer store had been adapted using the dynamic thermostat function as described in chapter 1 and 2.2.3.1. Adjusting the set temperature on a fixed value, based on the max. heat demand for a given building and location will definitely result in higher auxiliary demand and lower solar fraction.

The settings of the controller for charging the store with the solar collector was kept constant, see chapter 2.2.3.1.

The threshold temperature and the hysteresis for the controller of the external domestic hot water tank was kept constant and was chosen in a way, that the system always meets the load, see chapter 2.2.3.2.

All reference conditions were taken from the Milestone Reports from Subtask C. Correction factors for “imperfections”, e.g. for the thermal insulation had been included.

For all thermal insulation a thermal conductivity λ= 0.04 W/(mK) was assumed.

4.3 Results of calculations/simulations

The results are presented with a sheet with at least one figure for each of the parameters described in the summary above, Table 6. Each sheet has a diagram where the values for the three fractional savings indicators are shown. In most diagrams the values for the base case are shown as a vertical dotted black line. The scales for fractional savings and for the x-axis have been kept the same for all diagrams (except for a few cases), so that the diagrams can be compared more easily.

Passages with additional figures like column graphs summarize and describe sections and important differences to the base case.

All fractional energy savings are related to the Task 26 reference system. All calculations and results for System #9b, SolarNor presented in this report based on electric auxiliary heating. The electric auxiliary heating is implemented in the main buffer store and the external domestic hot water store, downstream the buffer. As agreed on in Task 26 for the evaluation of the simulation results an overall efficiency for all electricity used for auxiliary heating purpose of **0.9** was assumed. Corresponding to all other systems participating with system simulations, the efficiency for all other electricity demand, e.g. pumps or controllers was assumed to be **0.4**.

Sensitivity parameter:	Collector Size [m^2] (fixed store size 1.5 m^3)	5 – 30 m^2

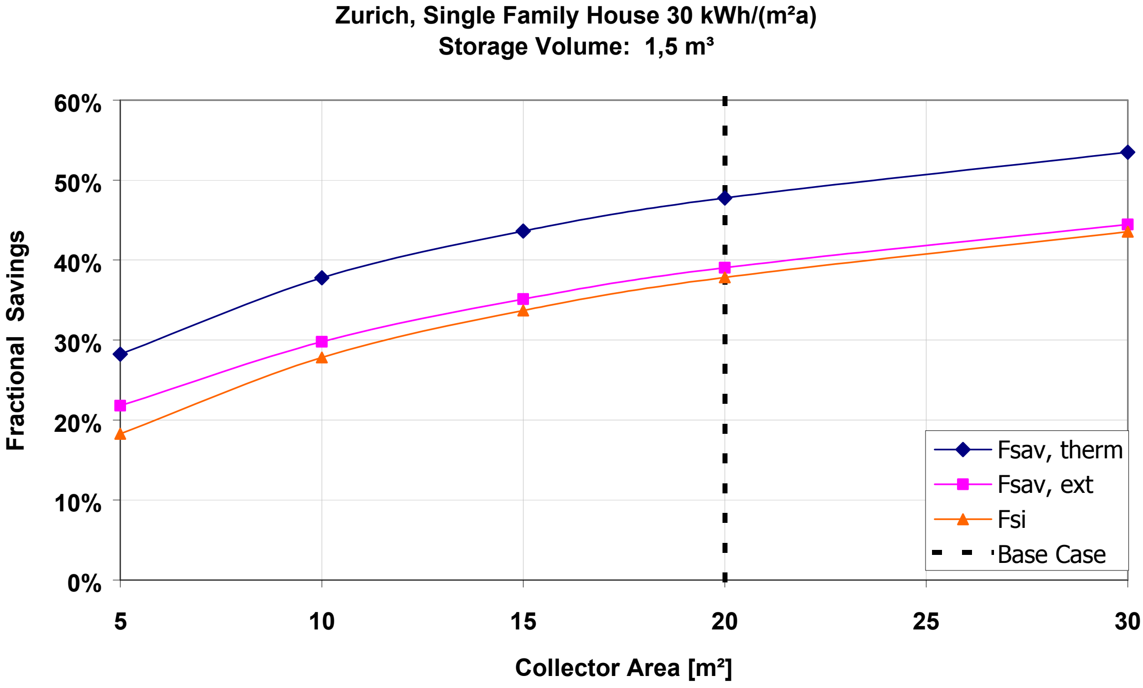


Fig. 8 Variation of fractional energy savings with collector size with fixed store volume of 1.5 m3. Single-family house 30 kWh/(m²a), Zurich.

Differences from Base Case

Collector size between 5 and 30 m².

Description of Results

As expected the increase of fractional savings, both the thermal and extended savings as well as the Fsi with increasing collector area decreases the larger the area. Fig. 8 shows the savings for a single-family house with a heat demand of 30 kWh/(m²a) located in Zurich. The savings for a single-family house at the same location with a heat demand of 60 kWh/(m²a) is shown in Fig. 9, for a single-family house with 100 kWh/(m²a) see Fig. 10 respectively.

Comments

None.

Sensitivity parameter:	Collector Size [m^2] (fixed store size 1.5 m^3)	5 – 30 m^2

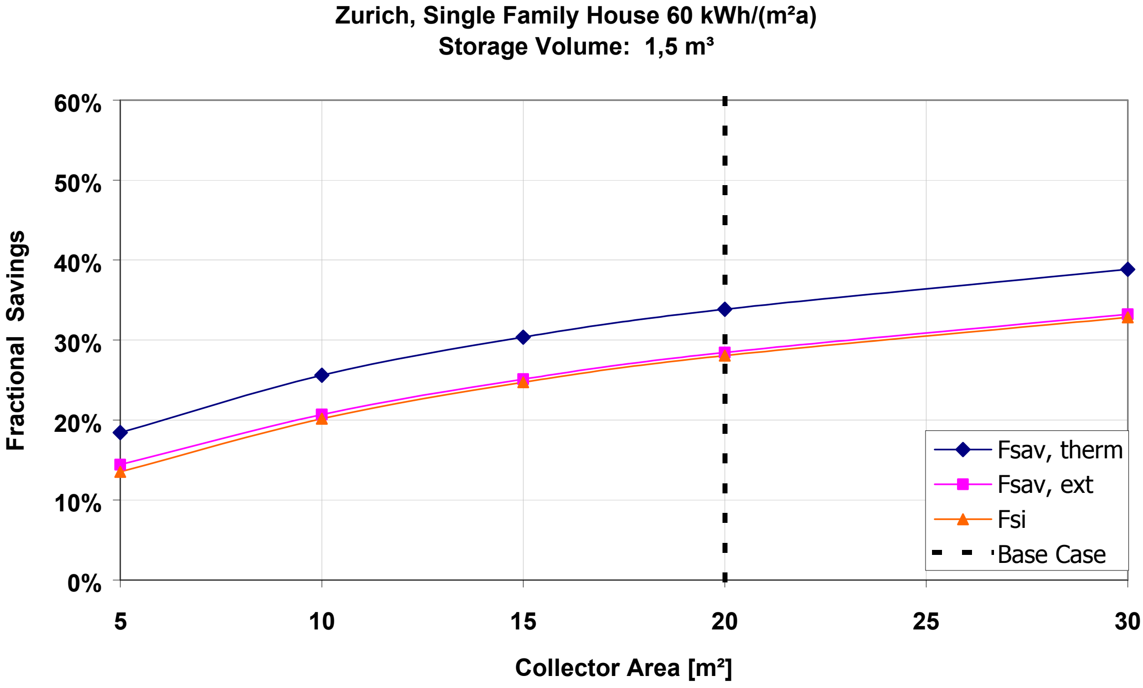


Fig. 9 Variation of fractional energy savings with collector size with fixed store volume of 1.5 m3. Single-family house 60 kWh/(m²a), Zurich.

Differences from Base Case
Collector size between 5 and 30 m².

Description of Results
As expected the increase of fractional savings, both the thermal and extended savings as well as the Fsi with increasing collector area decreases the larger the area. Fig. 9 show the savings for a single-family house with a heat demand of 60 kWh/(m²a) located in Zurich. There are few penalties incurred for the settings, so that $f_{si} \approx f_{sav,ext}$.
The savings for a single-family house at the same location with a heat demand of 30 kWh/(m²a) is shown in Fig. 8, for a single-family house with 100 kWh/(m²a) in Fig. 10 respectively.

Comments
None.

Sensitivity parameter:	Collector Size [m^2] (fixed store size 1.5 m^3)	5 – 30 m^2

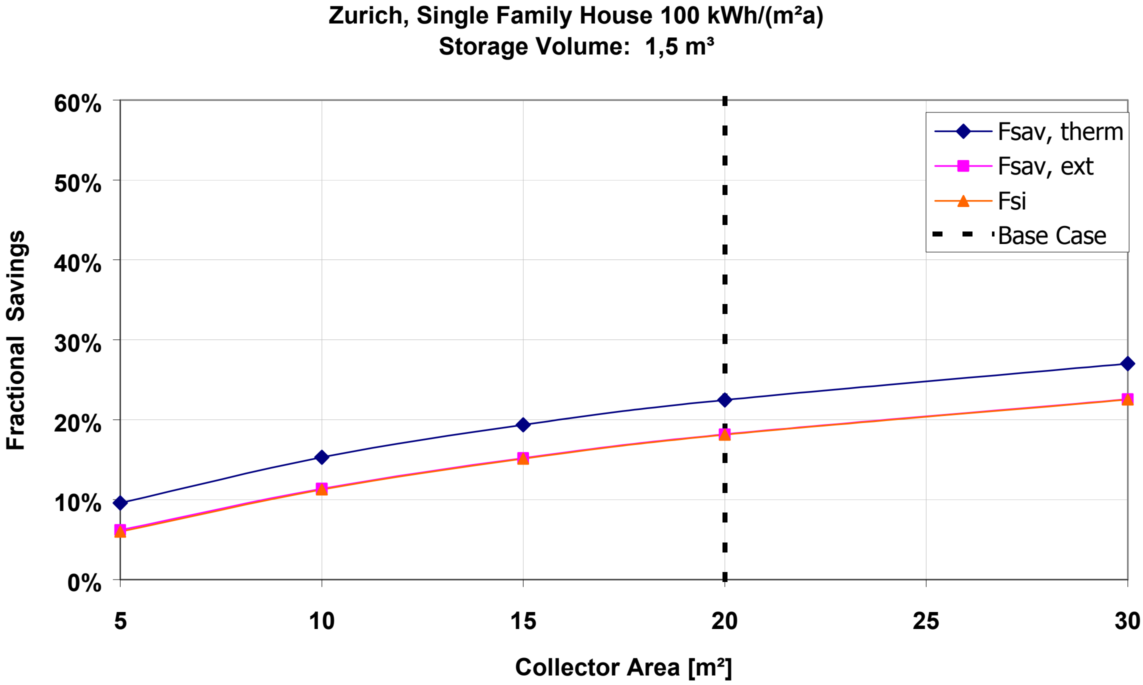


Fig. 10 Variation of fractional energy savings with collector size with fixed store volume of 1.5 m3. Single-family house 100 kWh/(m²a), Zurich.

Differences from Base Case
Collector size between 5 and 30 m².

Description of Results
As expected the increase of fractional savings, both the thermal and extended savings as well as the Fsi with increasing collector area decreases the larger the area. Fig. 10 show the savings for a single-family house with a heat demand of 100 kWh/(m²a) located in Zurich. There are very few penalties incurred for the settings, so that $f_{si} \approx f_{sav,ext}$.
The savings for a single-family house at the same location with a heat demand of 30 kWh/(m²a) is shown in Fig. 8, for a single-family house with 60 kWh/(m²a) in Fig. 9 respectively.

Comments
None.

Sensitivity parameter:	Base Case (collector area: 20 m², store size 1.5 m^3)	–

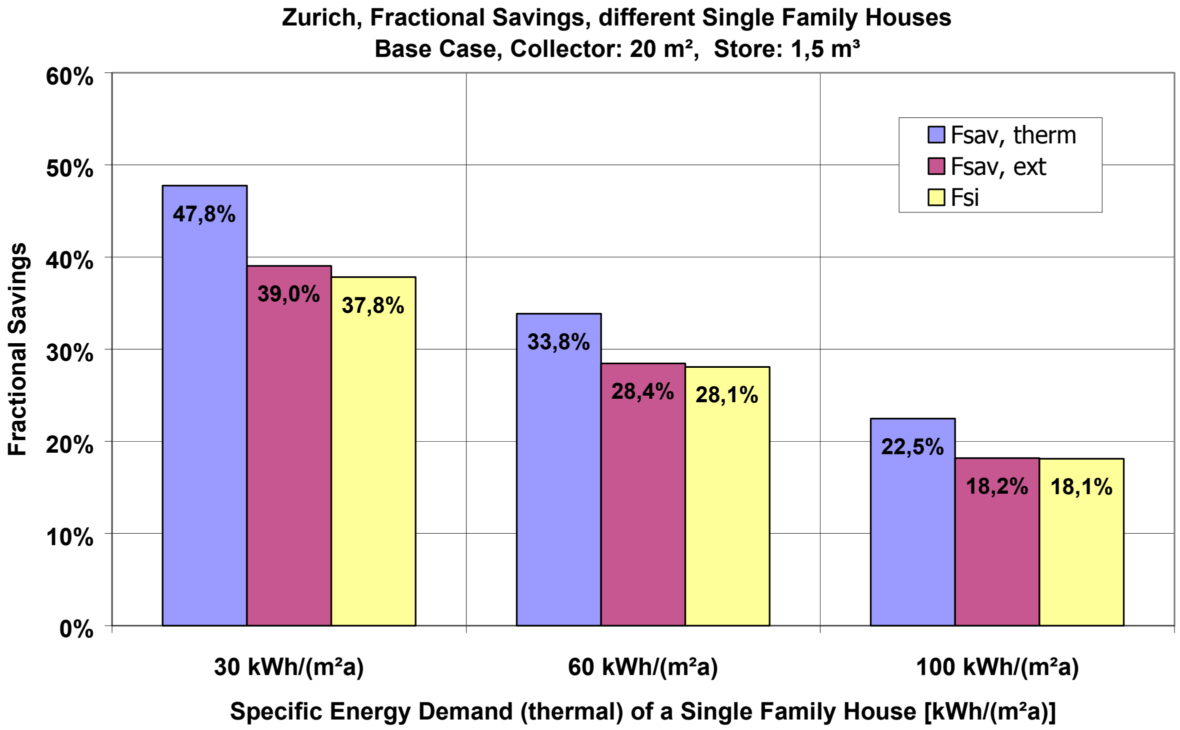


Fig. 11 Variation of fractional energy savings with fixed collector area of 20 m² and fixed store volume of 1.5 m3 (Base case).
Single-family houses with different heat demands, location Zurich.

Differences from Base Case

None.

Description of Results

The fractional savings (thermal and extended) and the Fsi decrease with increasing heat demand of the building.

Comments

None.

Sensitivity parameter:	Collector Size [m^2] (fixed store size 1.0 m^3)	5 – 30 m^2

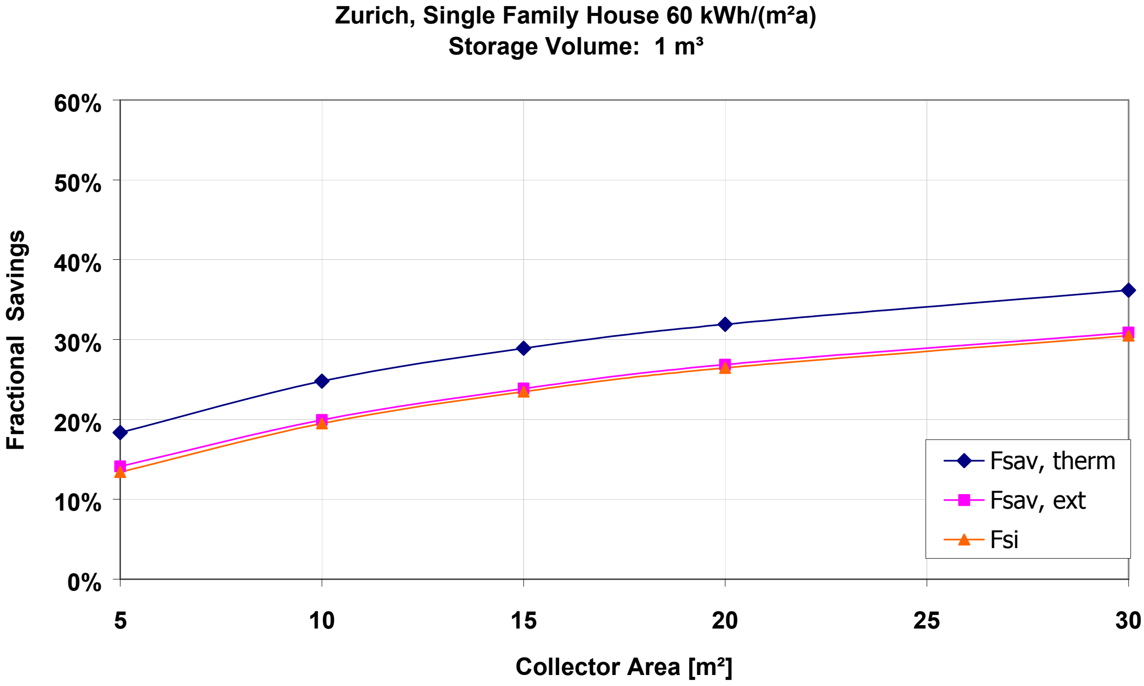


Fig. 12 Variation of fractional energy savings with collector size with fixed store volume of 1.0 m3. Single-family house 60 kWh/(m²a), Zurich.

Differences from Base Case

Collector size between 5 and 30 m², storage size 1.0 m³.

Description of Results

As expected the increase of fractional savings, both the thermal and extended savings as well as the Fsi with increasing collector area decrease the larger the area. Fig. 12 shows the savings for a single-family house with a heat demand of 60 kWh/(m²a) and a store volume of 1.0 m³, located in Zurich. There are few penalties incurred for the settings, so that $f_{si} \approx f_{sav,ext}$. The savings for the same single-family house at the same location with a store volume of 1,5 m³ are shown in Fig. 9, with 2 m³ volume in Fig. 13 and with 3 m³ volume in Fig. 14 respectively.

Comments

None.

Sensitivity parameter:	Collector Size [m^2] (fixed store size 2.0 m^3)	5 – 30 m^2

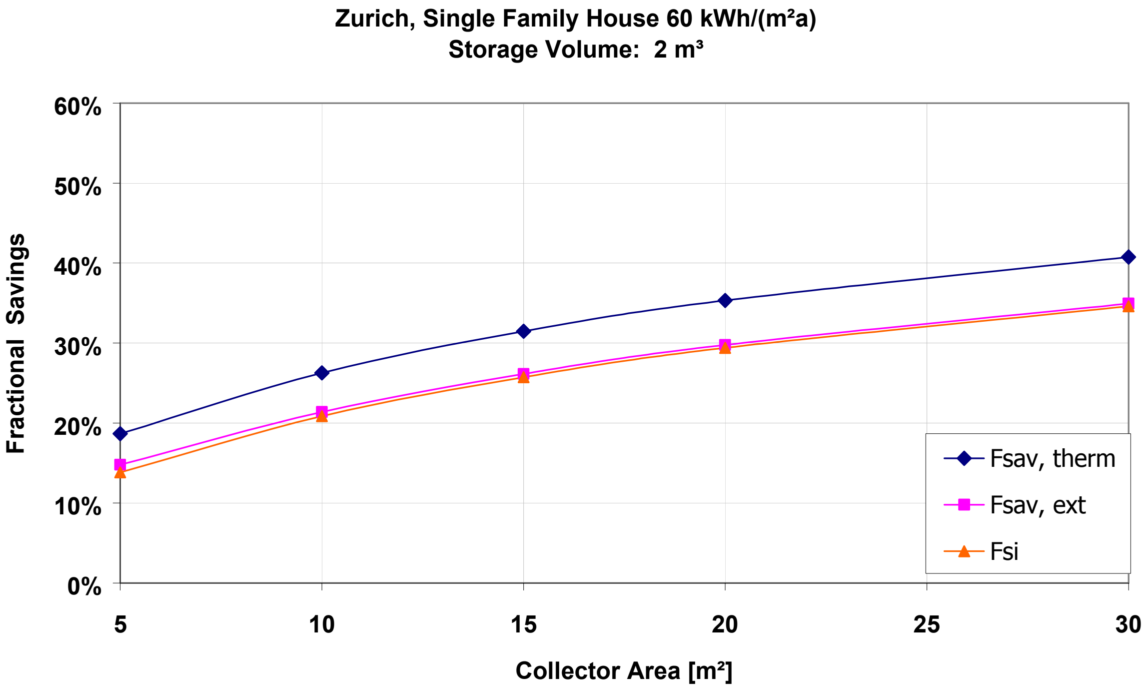


Fig. 13 Variation of fractional energy savings with collector size with fixed store volume of 2.0 m3. Single-family house 60 kWh/(m²a), Zurich.

Differences from Base Case

Collector size between 5 and 30 m², storage size 2.0 m³.

Description of Results

As expected the increase of fractional savings, both the thermal and extended savings as well as the Fsi with increasing collector area decrease the larger the area. Fig. 13 shows the savings for a single-family house with a heat demand of 60 kWh/(m²a) and a store volume of 2.0 m³, located in Zurich. There are few penalties incurred for the settings, so that $f_{si} \approx f_{sav,ext}$. The savings for the same single-family house at the same location with a store volume of 1,0 m³ are shown in Fig. 12, with 1,5 m³ volume in Fig. 9 and with 3 m³ volume in Fig. 14 respectively.

Comments

None.

Sensitivity parameter:	Collector Size [m^2] (fixed store size 3.0 m^3)	5 – 30 m^2

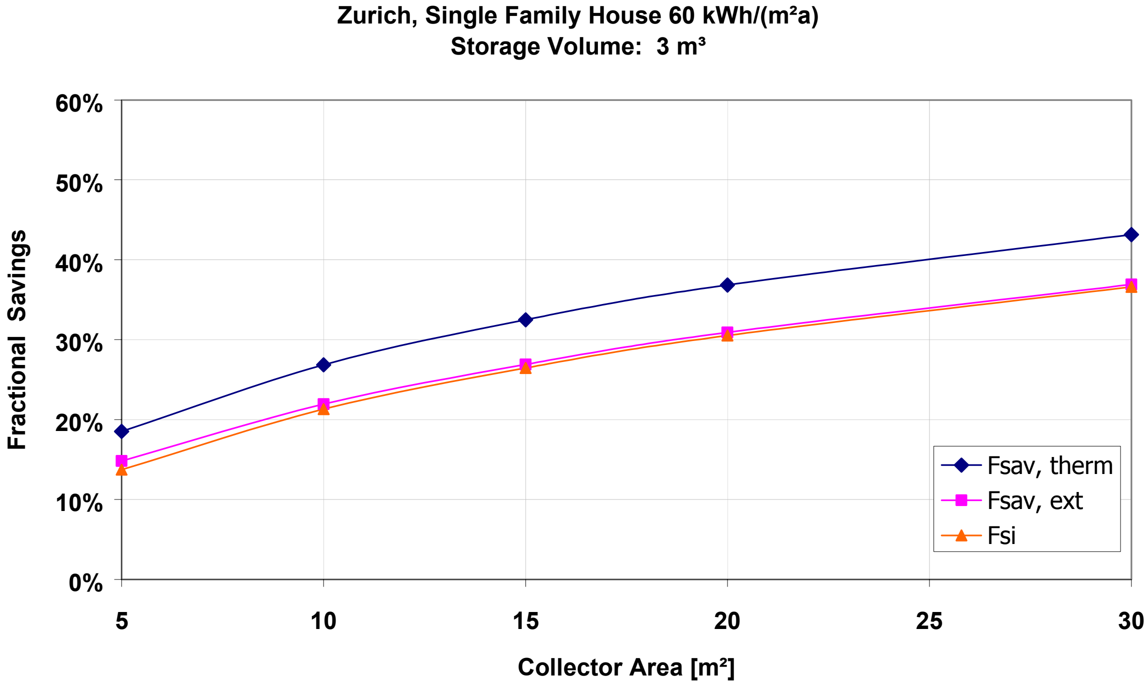


Fig. 14 Variation of fractional energy savings with collector size with fixed store volume of 3.0 m3. Single-family house 60 kWh/(m²a), Zurich.

Differences from Base Case

Collector size between 5 and 30 m², storage size 3.0 m³.

Description of Results

As expected the increase of fractional savings, both the thermal and extended savings as well as the Fsi with increasing collector area decrease the larger the area. Fig. 14 shows the savings for a single-family house with a heat demand of 60 kWh/(m²a) and a store volume of 3.0 m³, located in Zurich. There are few penalties incurred for the settings, so that $f_{si} \approx f_{sav,ext}$. The savings for the same single-family house at the same location with a store volume of 1,0 m³ are shown in Fig. 12, with 1,5 m³ volume in Fig. 9 and with 2 m³ volume in Fig. 13 respectively.

Comments

None.

Sensitivity parameter:	Store Volume [m^3] (fixed collector area 20 m^2)	1 – 3 m^3

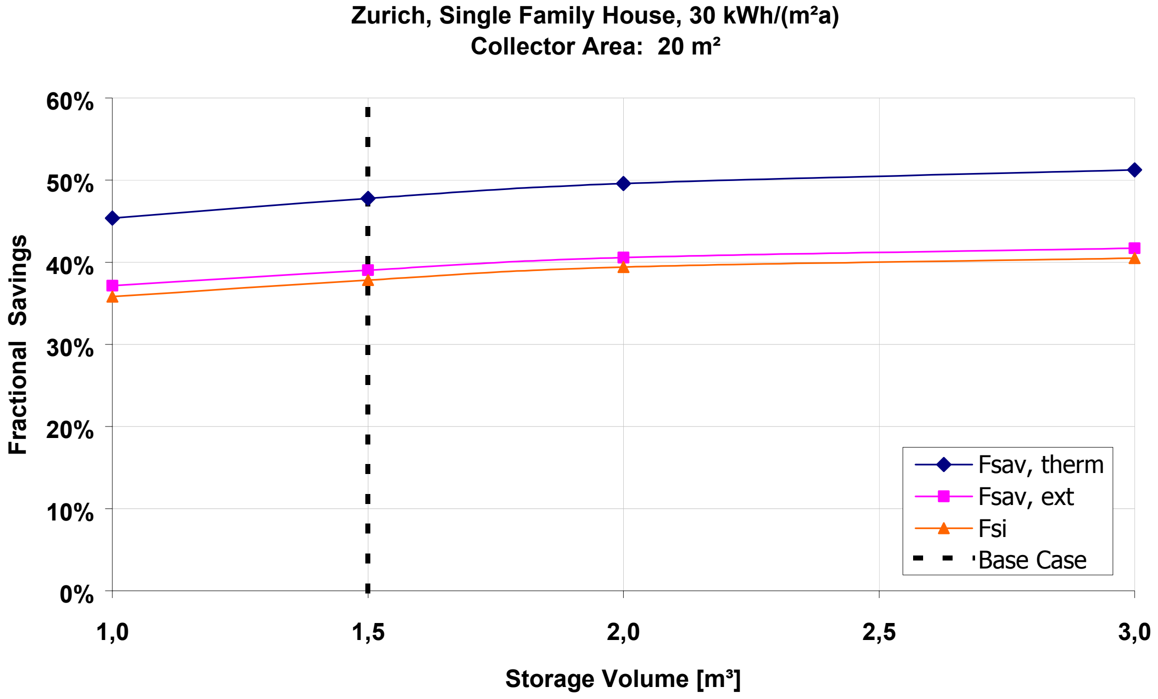


Fig. 15 Variation of fractional energy savings with store volume with fixed collector area of 20 m^2. Single-family house 30 kWh/(m^2a), Zurich.

Differences from Base Case
Store volume between 1 and 3 m^3.

Description of Results
Regarding the fractional savings the results of the calculations in Fig. 15 do not show an optimum for a specific storage volume but the increase of the savings with store volumes for more than 2 m^3 is quite small.

Comments
None.

Sensitivity parameter:	Store Volume [m^3] (fixed collector area 20 m^2)	1 – 3 m^3

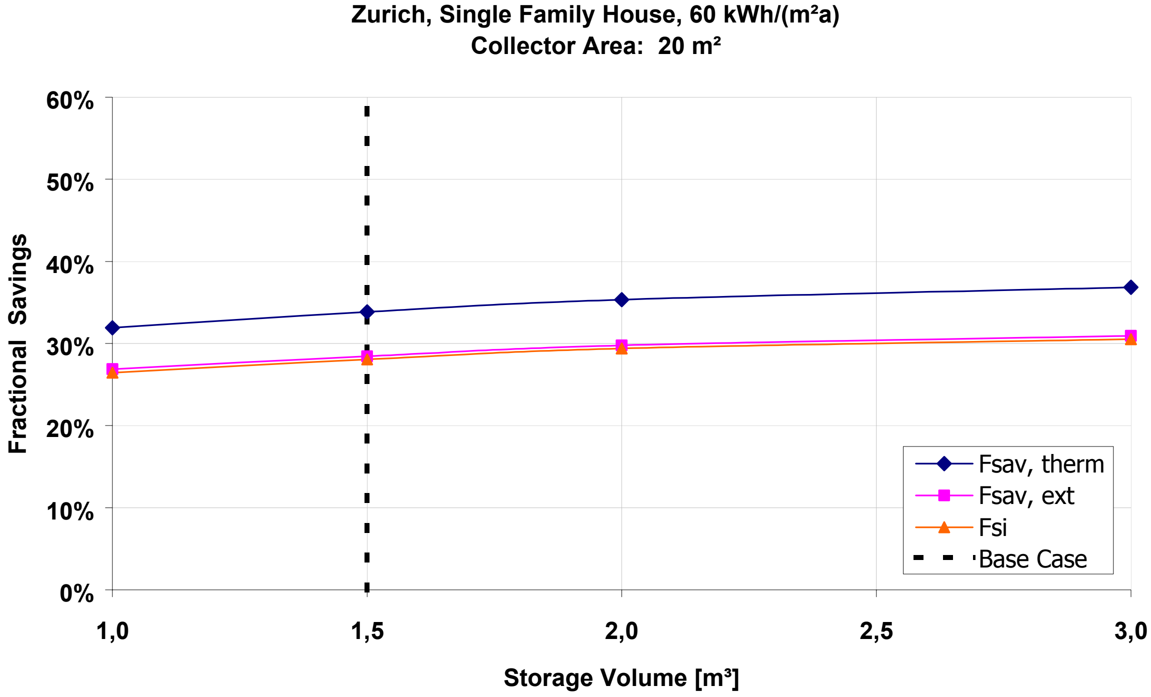


Fig. 16 Variation of fractional energy savings with store volume with fixed collector area of 20 m². Single-family house 60 kWh/(m²a), Zurich.

Differences from Base Case

Store volume between 1 and 3 m^3.

Description of Results

Regarding the fractional savings the results of the calculations in Fig. 16 do not show an optimum for a specific store volume but the increase of the savings with larger store volumes is decreasing. Only few penalties incurred for the settings, so that $f_{si} \approx f_{sav,ext}$.

Comments

None.

Sensitivity parameter:	Store Volume [m^3] (fixed collector area 20 m²)	1 – 3 m³

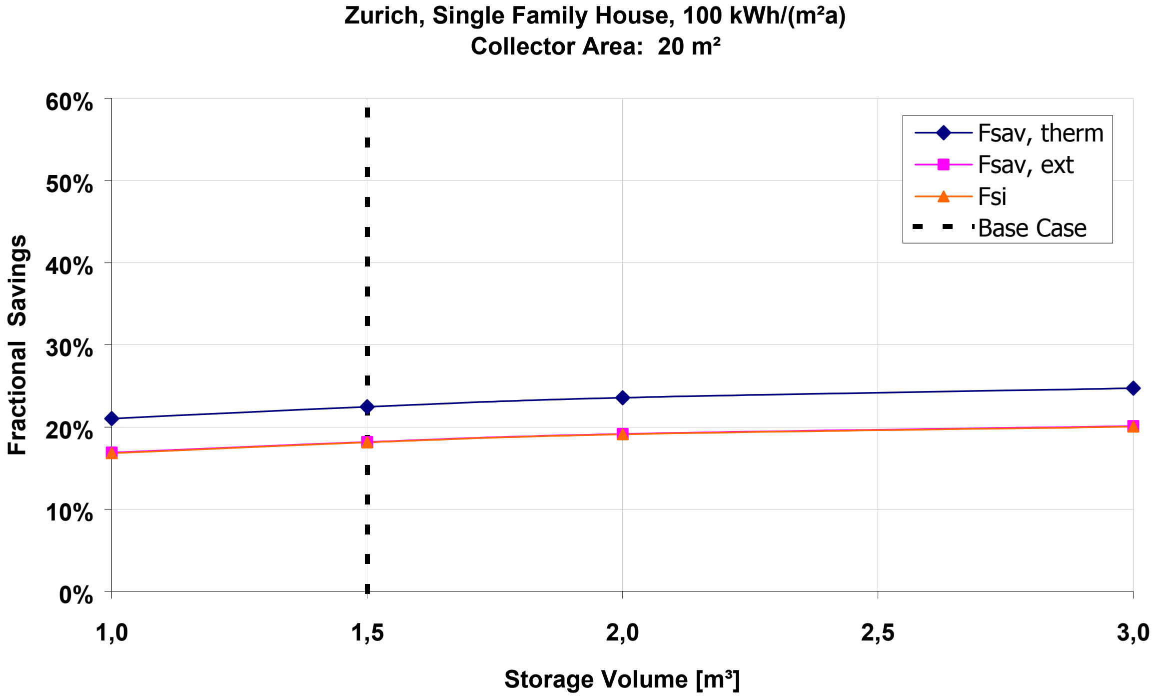


Fig. 17 Variation of fractional energy savings with store volume with fixed collector area of 20 m². Single-family house 100 kWh/(m²a), Zurich.

Differences from Base Case
Store volume between 1 and 3 m³.

Description of Results
Regarding the fractional savings the results of the calculations in Fig. 17 do not show an optimum for a specific store volume but as expected the increase of the savings with larger store volumes is decreasing. Very few penalties incurred for the settings, so that $f_{si} \approx f_{sav,ext}$.

Comments
From Fig. 17 it can be stated, that for the single-family house with a heat demand of 100 kWh/(m²a) located in Zurich the dimensions of the base case (collector area: 20 m², store volume 1.5 m³) fit quite well.

Sensitivity parameter:	Base Case (collector area: 20 m², store size 1.5 m^3)	–

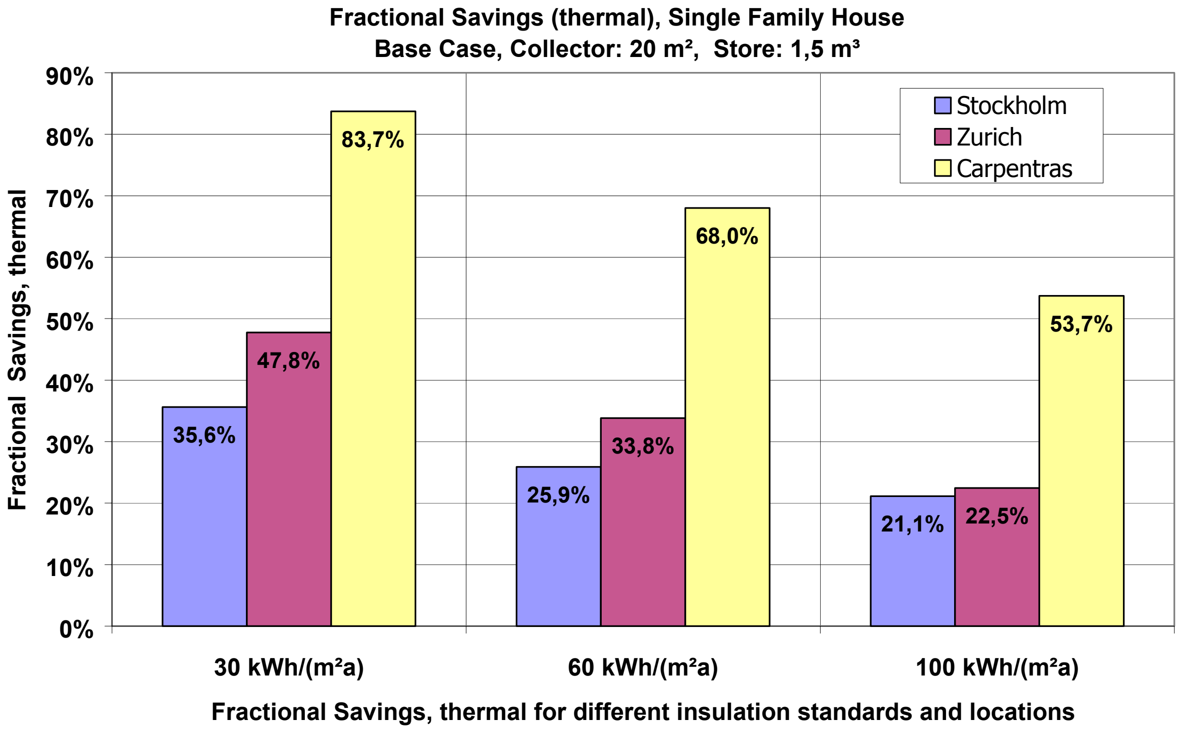


Fig. 18 Fractional energy savings (thermal) for different insulation standards and locations. System design: Base Case.

Differences from Base Case
None.

Description of Results
The fractional savings for the base case of System #9b decrease with increasing heat demand of the building. For the different insulation standards the savings for a building located in Carpentras are the highest. For Zurich the fractional savings for the different buildings are approximately half of the values for Carpentras. For Stockholm the lowest fractional savings are achieved. The reductions compared to Zurich are another 12 %pts for the 30 kWh/(m²a) house, 8 %pts for the 60 kWh/(m²a) house and appr. 1.5 %pts for a house with a heat demand of 100 kWh/(m²a).

Comments
None.

Sensitivity parameter:	Collector Size [m^2] and Specific Store Volume [dm³/m²]	10 – 30 m^2 30 – 300 dm³/m²

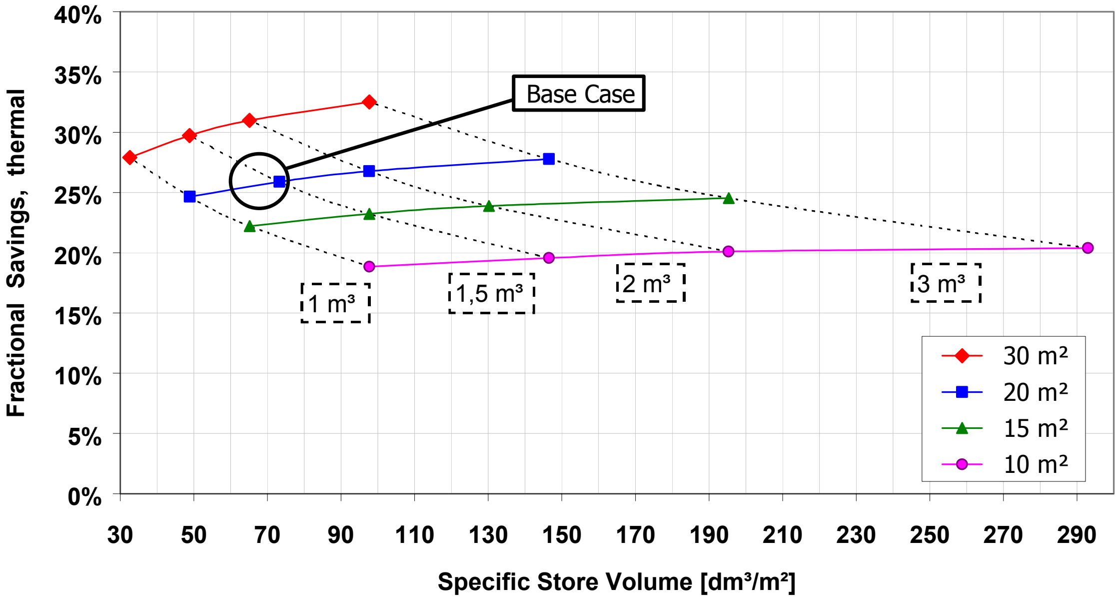


Fig. 19 Variation of fractional energy savings (thermal) with specific store volume for different collector areas. Single-family house 1000 kWh/(m²a), Stockholm.

Differences from Base Case

Specific store volume between 30 and 300 dm³/m², collector area 10, 15, 20 and 30 m².

Description of Results

As expected the fractional savings (thermal) for larger collector areas are higher than for smaller ones. The savings also increase with increasing specific store volume while the increase for larger collector areas is significant higher than for smaller ones. In all cases the increasing savings with larger specific store volumes decrease the larger the specific store volumes.

Comments

None.

Sensitivity parameter:	Collector Size [m²] and Specific Store Volume [dm³/m²]	10 – 30 m² 30 – 300 dm³/m²

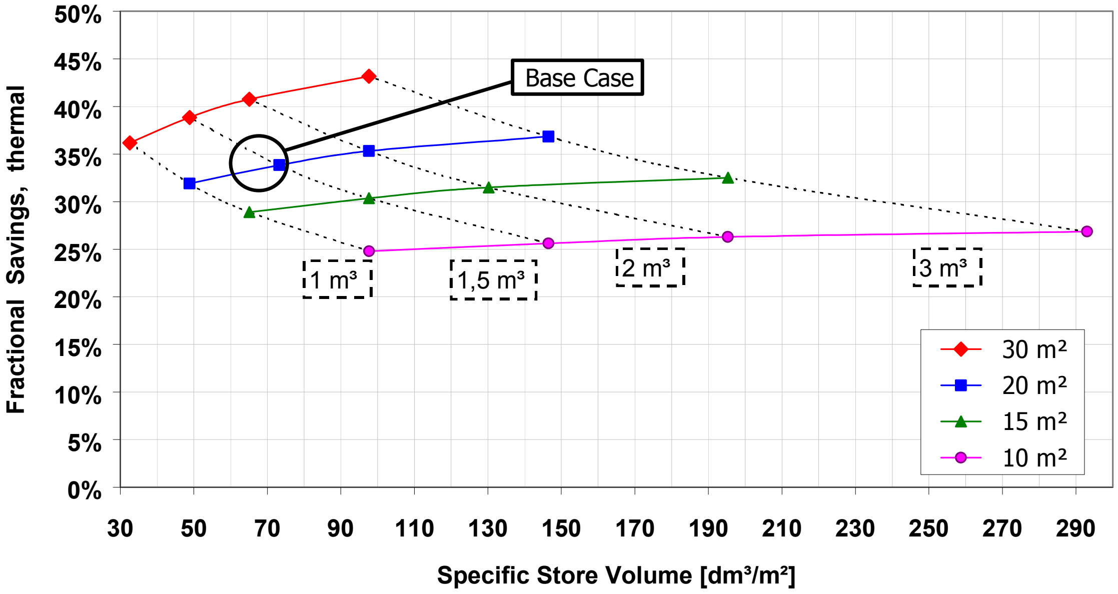


Fig. 20 Variation of fractional energy savings (thermal) with specific store volume for different collector areas. Single-family house 60 kWh/(m²a), Zurich.

Differences from Base Case

Specific store volume between 30 and 300 dm³/m², collector area 10, 15, 20 and 30 m².

Description of Results

As expected the fractional savings (thermal) for larger collector areas are higher than for smaller ones. The savings also increase with increasing specific store volume while the increase for larger collector areas is significant higher than for smaller ones. In all cases the increasing savings with larger specific store volumes decrease the larger the specific store volumes.

Comments

None.

Sensitivity parameter:	Collector Size [m^2] and Specific Store Volume [dm³/m²]	10 – 30 m^2 30 – 300 dm³/m²

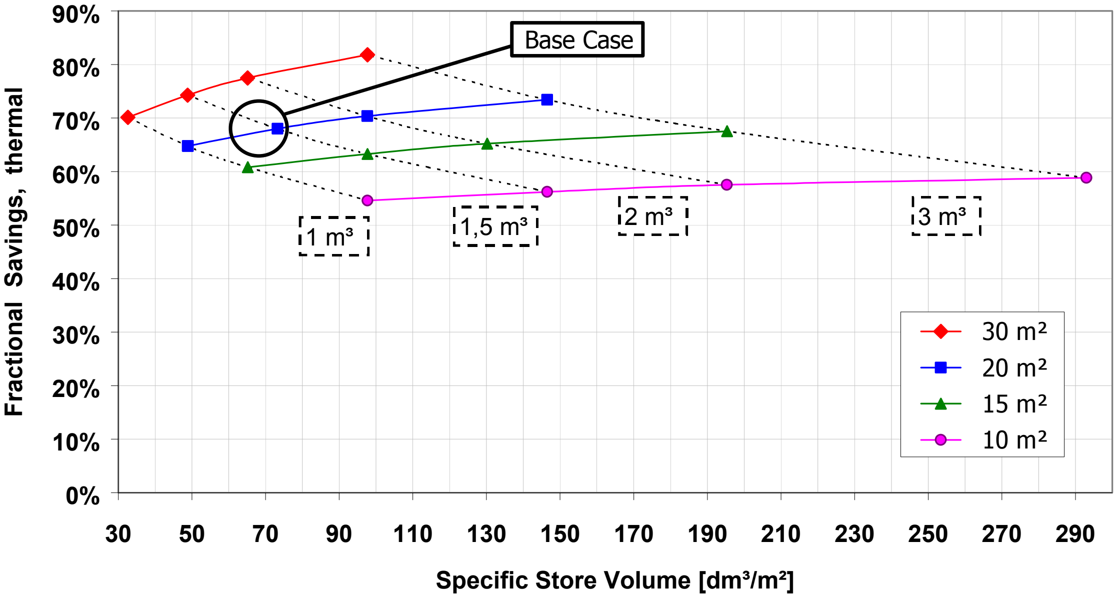


Fig. 21 Variation of fractional energy savings (thermal) with specific store volume for different collector areas. Single-family house 30 kWh/(m²a), Carpentras.

Differences from Base Case

Specific store volume between 30 and 300 dm³/m², collector area 10, 15, 20 and 30 m².

Description of Results

As expected the fractional savings (thermal) for larger collector areas are higher than for smaller ones. The savings also increase with increasing specific store volume while the increase for larger collector areas is significant higher than for smaller ones. In all cases the increasing savings with larger specific store volumes decrease the larger the specific store volumes.

Comments

None.

Sensitivity parameter:	Base Case (collector area: 20 m², store size 1.5 m^3)	–

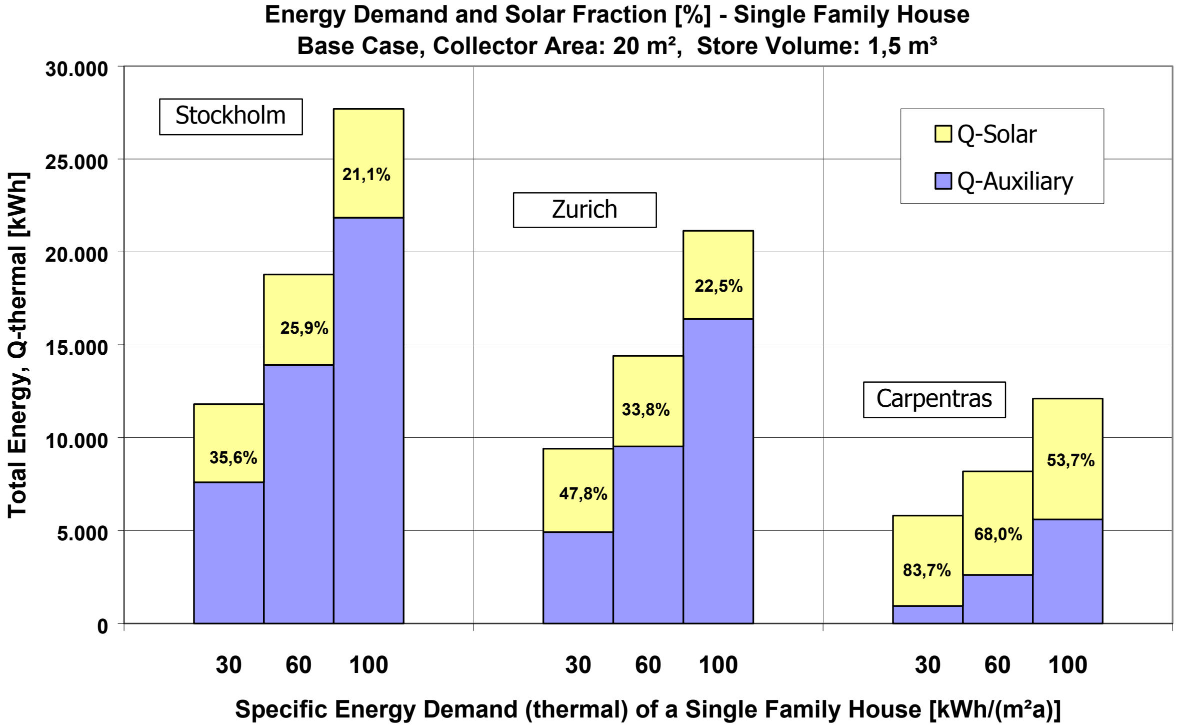


Fig. 22 Total Energy (Q-thermal) and Solar Fraction for different insulation standards and locations. System design: Base Case.

Differences from Base Case

None.

Description of Results

The values of the total energy demand for the different insulation standards are the highest for Stockholm and the lowest for Carpentras. The numbers for Zurich are in between. The total energy demand (Q-thermal) increase and the solar fraction for the base case decreases with increasing heat demand of the building.

For the different insulation standards the solar fractions for buildings located in Carpentras are the highest. For Zurich the solar fractions for the different buildings are approximately half of the values for Carpentras. For Stockholm the lowest solar fractions are achieved. The reductions compared to Zurich are another 12 %pts for the 30 kWh/(m²a) house, 8 %pts for the 60 kWh/(m²a) house and appr. 1.5 %pts for a house with a heat demand of 100 kWh/(m²a).

Comments

None.

Sensitivity parameter:	Base Case (collector area: 20 m², store size 1.5 m^3)	–

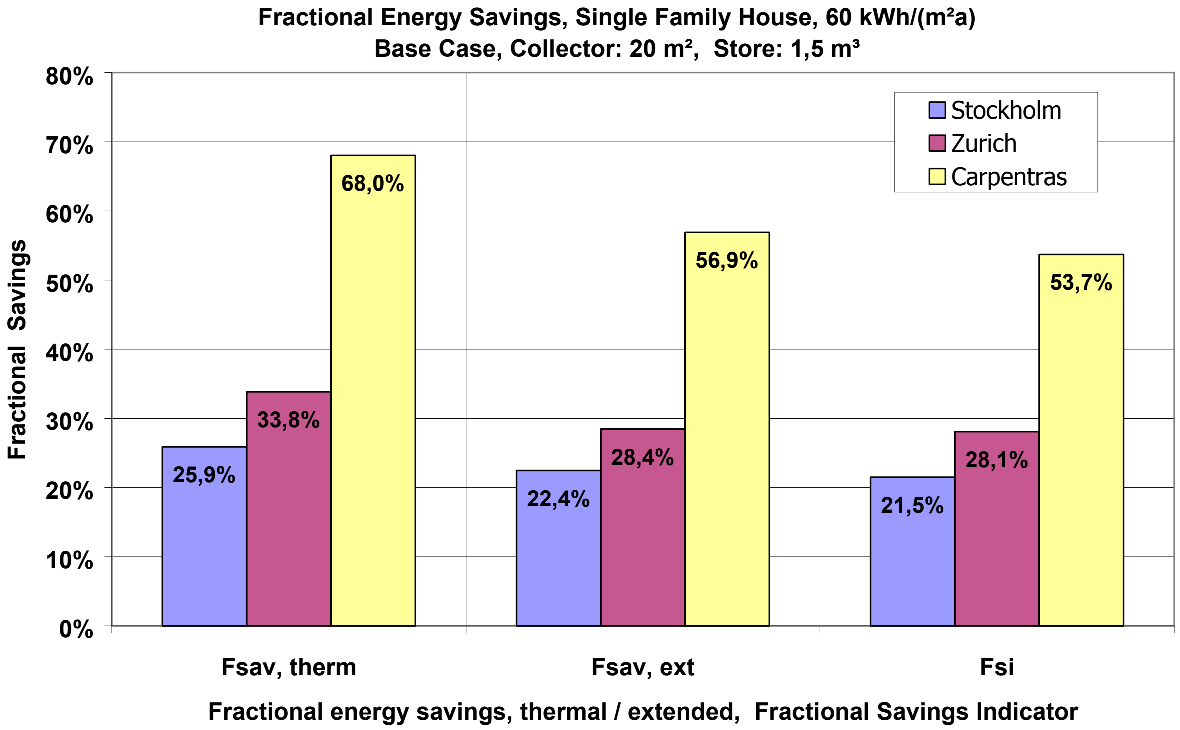


Fig. 23 Fractional energy savings and FSI for a house with a heat demand of 60 kWh/(m²a) and different locations. System design: Base Case.

Differences from Base Case

None.

Description of Results

The highest fractional savings are achieved for Carpentras, the lowest for Stockholm. The fractional savings for Zurich are in between but much closer to the values for Stockholm than to those for Carpentras.

Comments

None.

Sensitivity parameter:	Base Case (collector area: 20 m², store size 1.5 m^3)	–

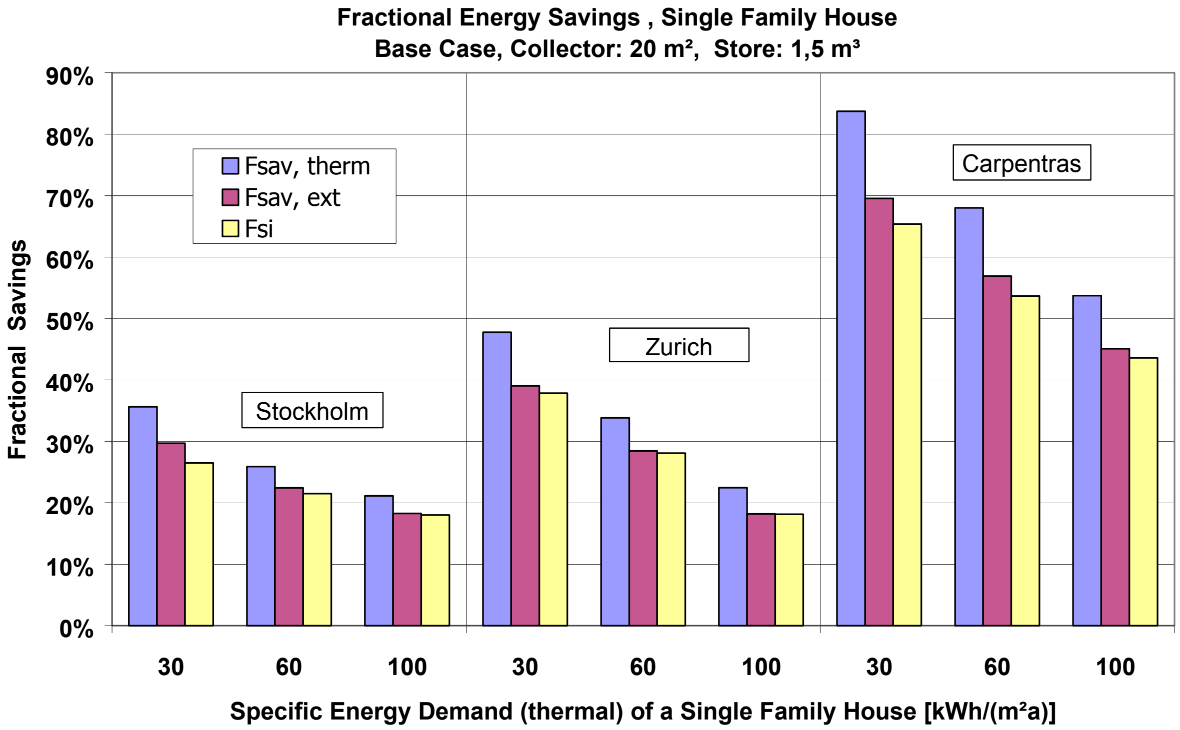


Fig. 24 Fractional energy savings and FSI for houses with different insulation standards and different locations. System design: Base Case.

Differences from Base Case
None

Description of Results
The highest fractional savings are achieved for Carpentras with decreasing values for houses with increasing specific heat demand. As expected the lowest fractional savings are achieved for Stockholm, while the increase of the specific heat demand of the building results in decreasing savings. The fractional savings for Zurich are in between, much closer to the values for Stockholm than to those for Carpentras.

Comments
None.

Sensitivity parameter:	Base Case (collector area: 20 m², store size 1.5 m^3)	–

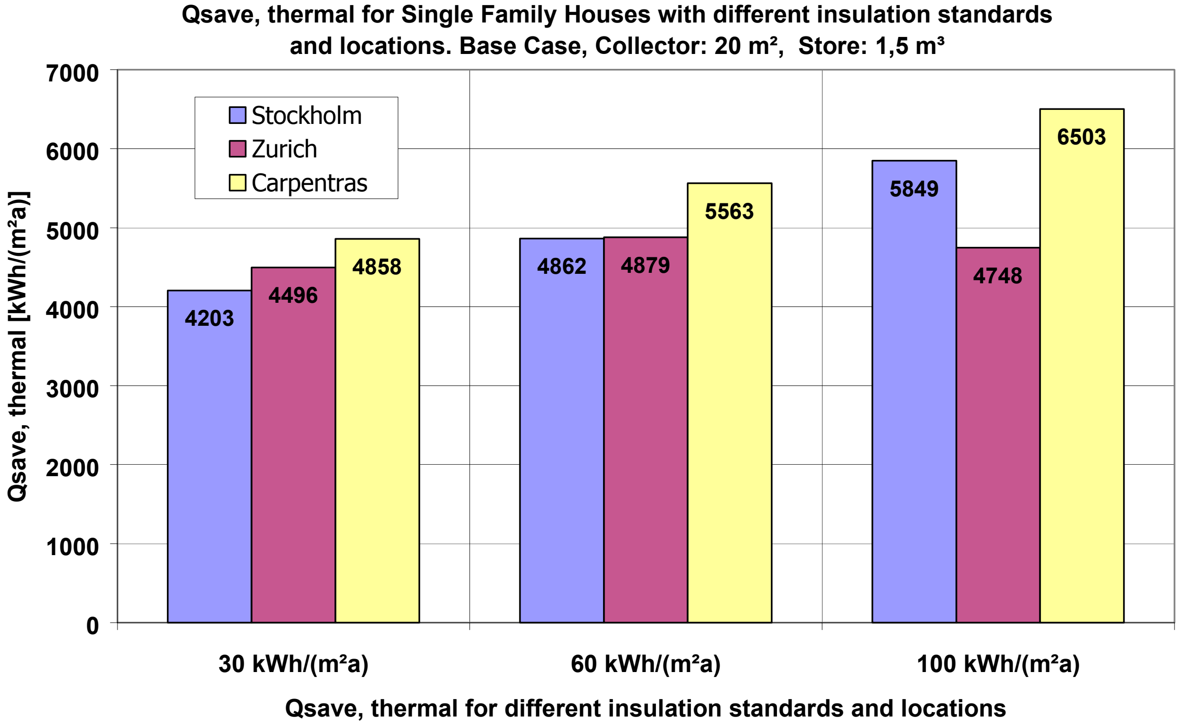


Fig. 25 Qsave, therm for houses with different insulation standards and different locations. System design: Base Case.

Differences from Base Case

None

Description of Results

Fig. 25 show the variation in thermal savings Qsave (kWh) for the base case with a collector area of 20 m² and a store volume of 1.5 m³ for different insulation standards (heating loads) and different climates. The highest savings are achieved for Carpentras with decreasing values for houses with increasing specific heat demand. It can be stated, that for the chosen climates an increase of the load due to a less insulated houses (SFH100 compared toSFH60 and SFH30) in principle leads to higher energy savings, but in the opposite to lower fractional energy savings, see Fig. 26. This means the higher the load, the more "efficient" the solar loop works. On the other hand, of course, the auxiliary energy increases. Note that for a given house the increase in energy savings between the different climates is not very high.

Comments

The decrease in the thermal savings between the Zurich 60 and 100 kWh/(m²a) house results from unfavourable set temperatures and working periods of the auxiliary in this particularly case. It can be seen, that for Zurich also the increase between the 30 and 60 kWh/(m²a) house is quite low.

Sensitivity parameter:	Base Case (collector area: 20 m^2, store size 1.5 m^3)	–

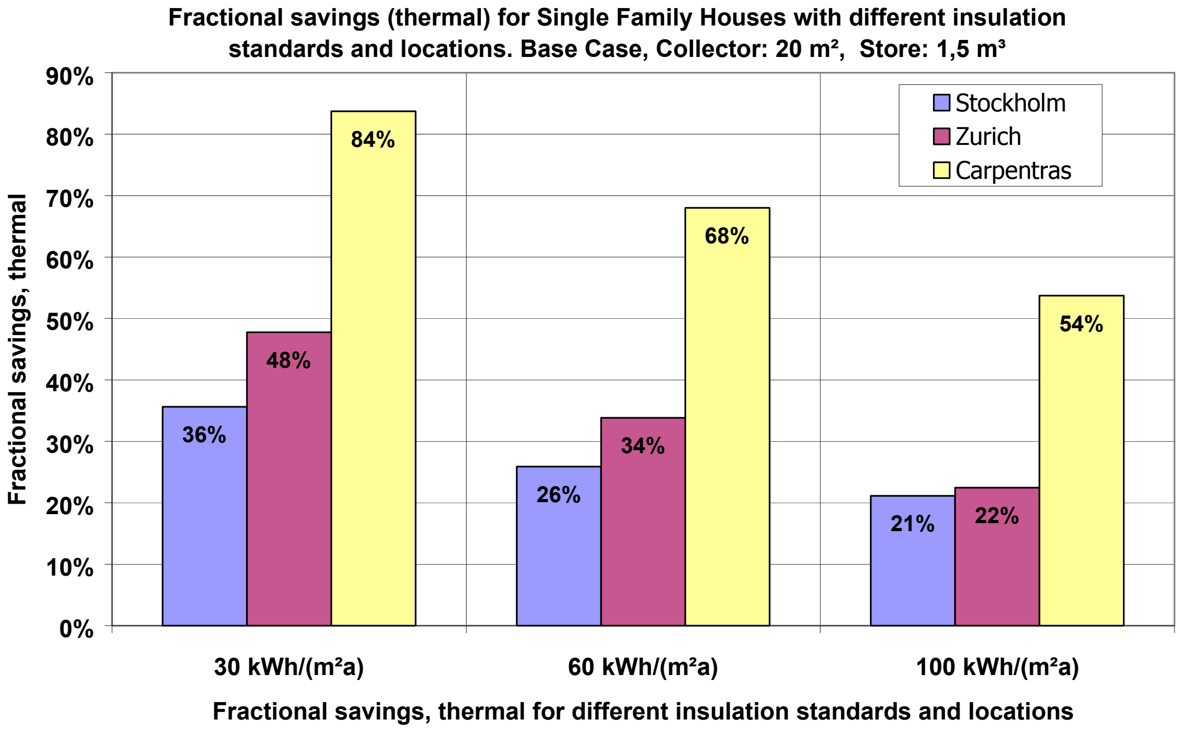


Fig. 26 Fractional savings (thermal) for houses with different insulation standards and different locations. System design: Base Case.

Differences from Base Case

None.

Description of Results

Fig. 26 show the fractional energy savings (thermal) for the same systems, loads and locations as they were basis for Fig. 25. The numbers are already given in Fig. 18. As stated before, for a chosen house the amount of energy saved by a solar combisystem doesn't change that much according to the climate, which is not the case for fractional energy savings. This means that the same combisystem installed in an "identical" house will provide more or less the same energy savings and consequently the same gas or oil savings. In other words, it is as profitable to install combisystems anywhere in Europe.

Comments

None.

5 Analysis using FSC

The following figures show the analysis of System #9b based on the FSC method, presented in [6].

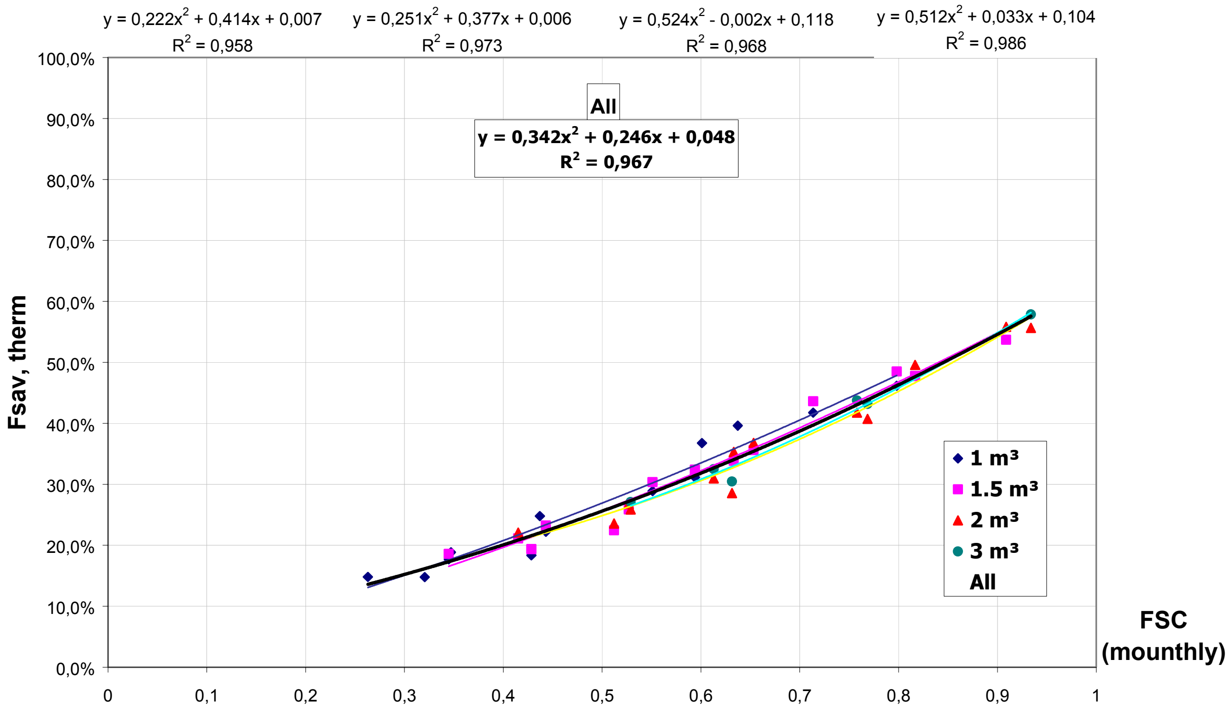


Fig. 27 Fsav,therm as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses.

Fig. 27 is based on 4 different collector areas. The different sizes are 10, 15, 20 and 30 m² of aperture area. In the same way the storage volume of the central buffer tank was changed. The chosen tank volumes were 1, 1.5, 2 and 3 m³. According to the definitions and limits of the FSC method the different collector areas, storage sizes and insulation standards of the buildings as well as three different climates were combined which each other in all possible ways, see Fig. 6. For description of the FSC method see [6].

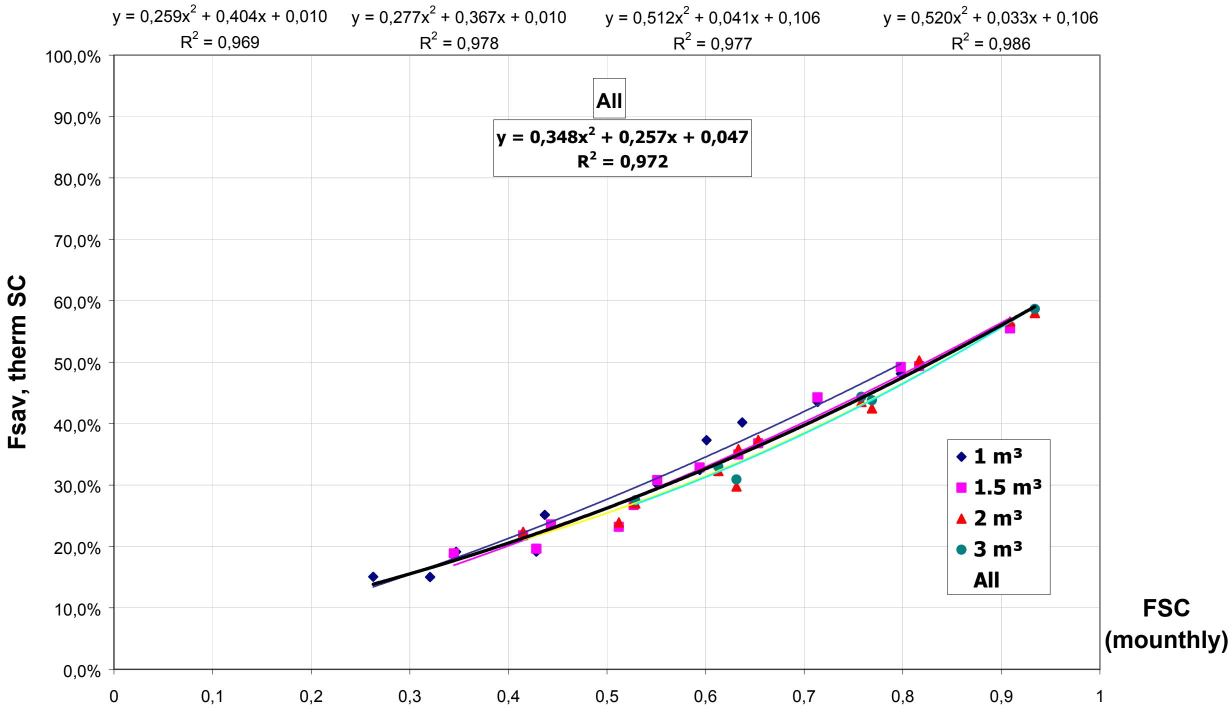


Fig. 28 Fsav,therm SC as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses.

The data for Fig. 28 correspond to those from Fig. 27. In addition a storage capacity correction factor SC is added. The SC factor is described within the FSC method [6].

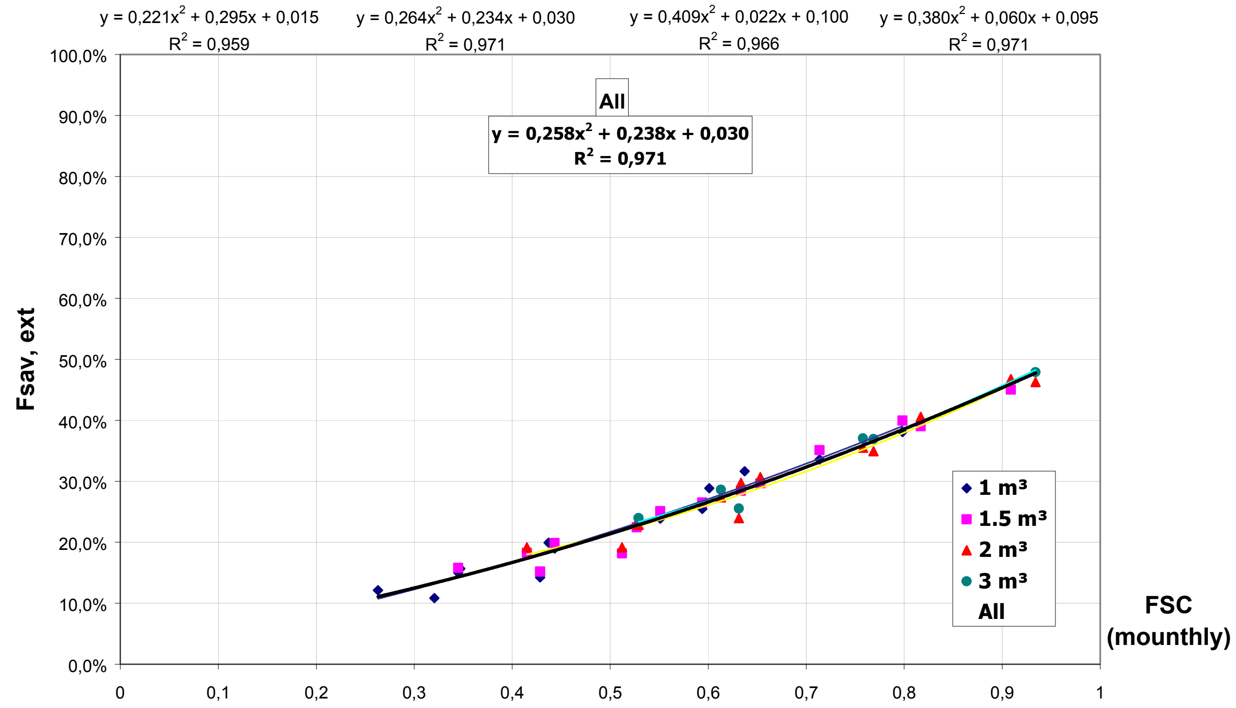


Fig. 29 Fsav,ext as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses.

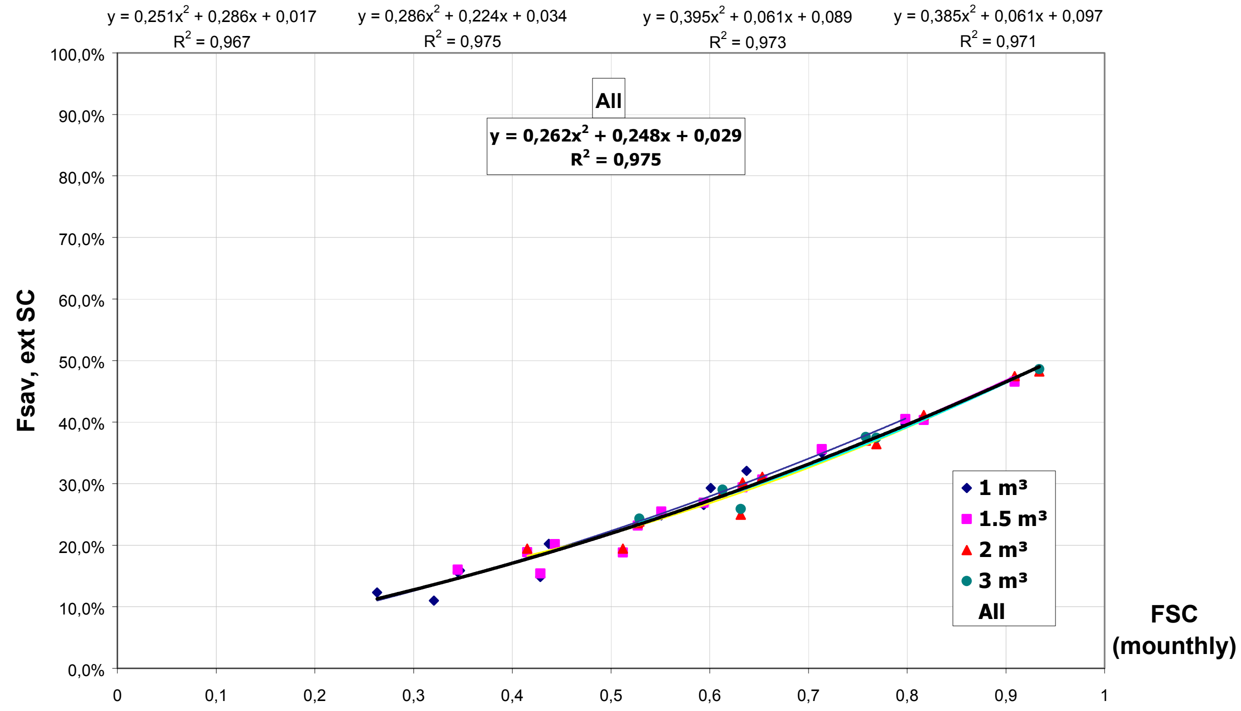


Fig. 30 Fsav ext SC as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses. In addition a storage capacity correction factor SC is added.

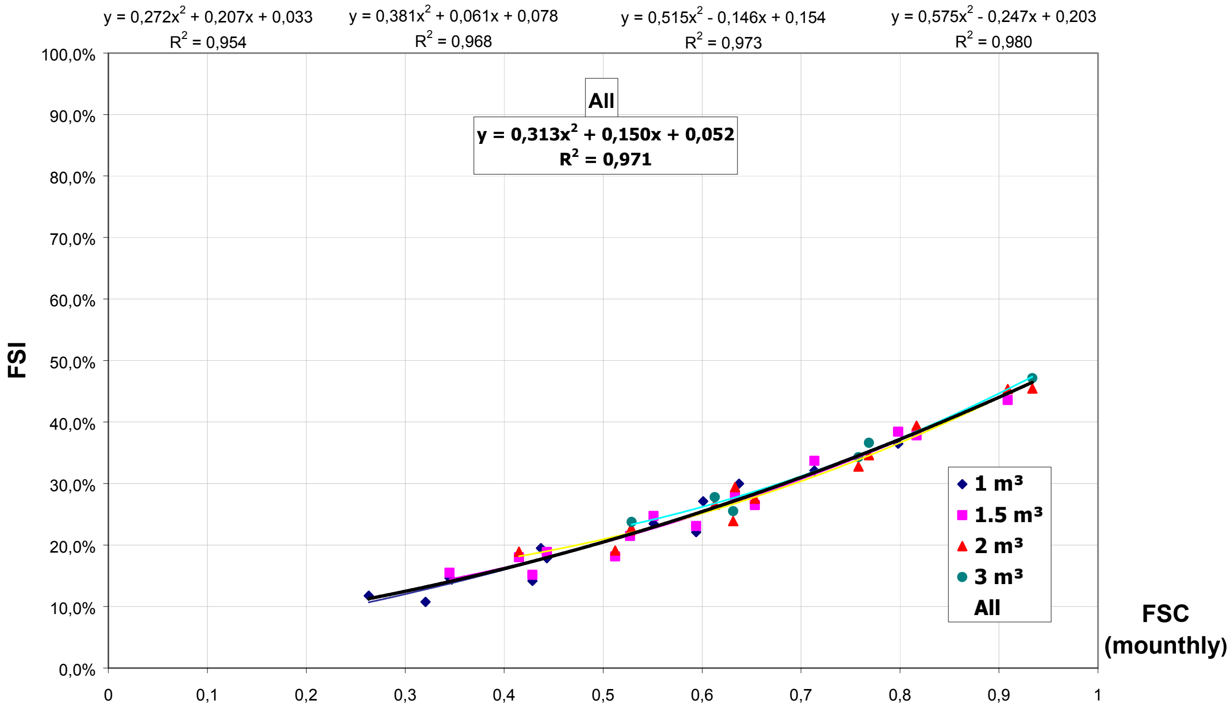


Fig. 31 FSI as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses.

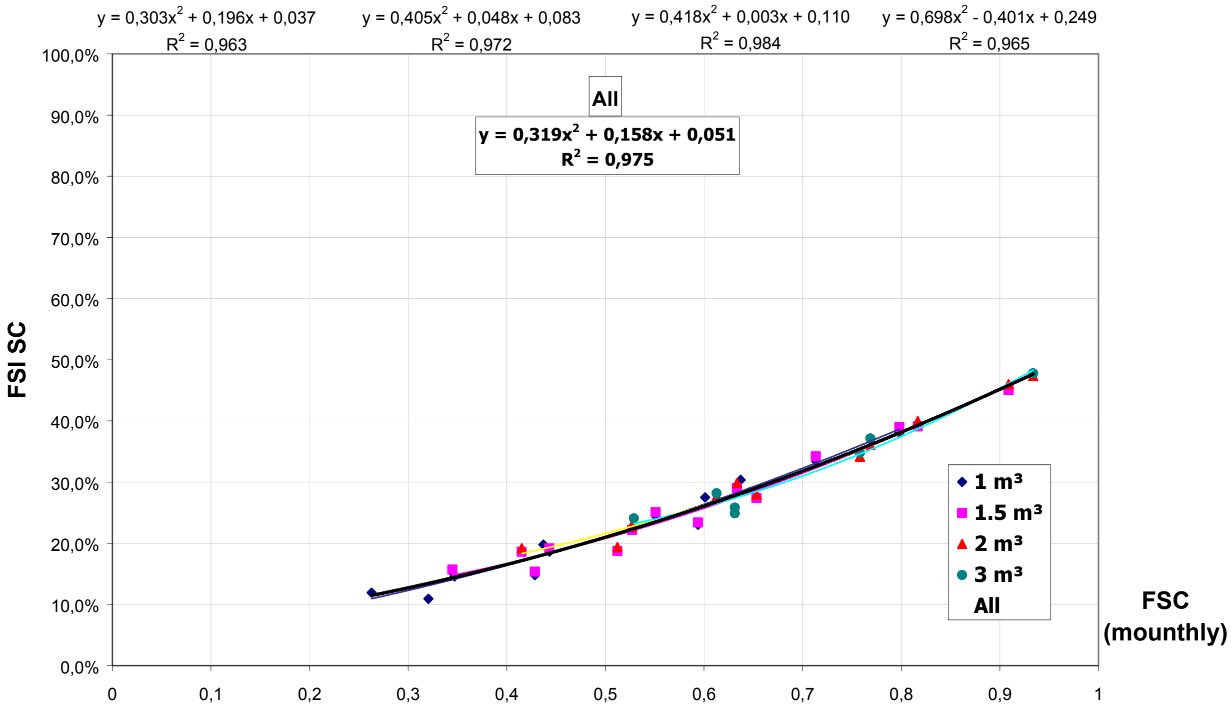


*Fig. 32 FSI SC as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and3 loads (30, 60, 100 kWh/(m²a)) Calculations for single-family houses.
In addition a storage capacity correction factor SC is added.*

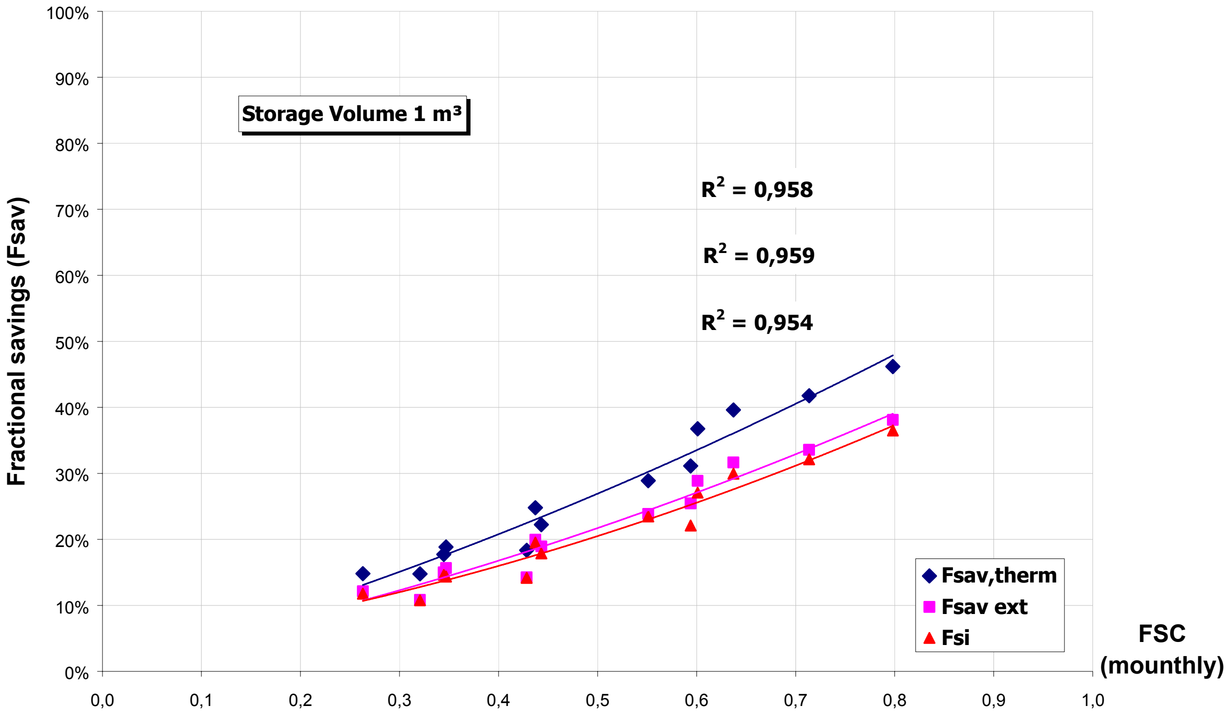


Fig. 33 Fsav, therm, Fsav, ext and FSI as a funktion of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses with a storage size of 1 m³.

In Fig. 33 four different collector sizes with 10, 15, 20 and 30 m² aperture area are combined with a 1 m³ storage. The calculations had been carried out for Stockholm, Zurich and Carpentras for single-family houses with heating loads of 30, 60 and 100 kWh/(m²a).

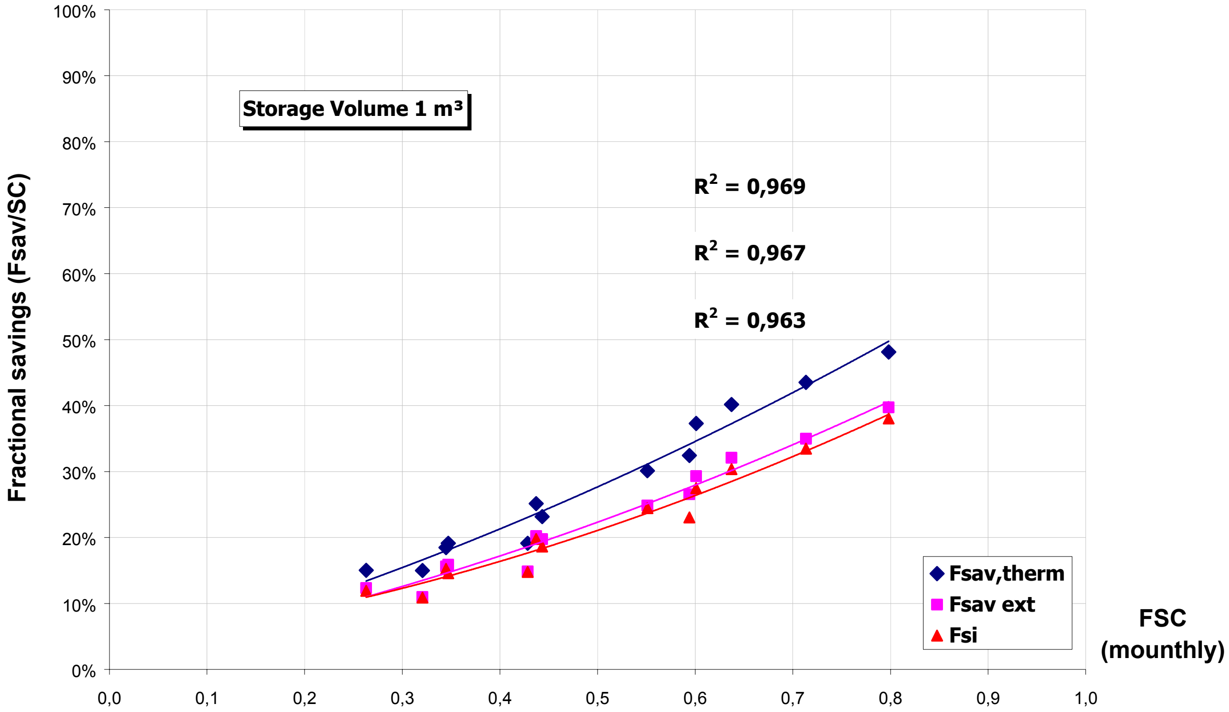


Fig. 34 Fsav,therm, Fsav,ext and FSI as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses with a storage size of 1 m³. Including a storage capacity correction factor SC.

The data of Fig. 34 correspond with those from Fig. 33. In addition a storage capacity correction factor SC is added.

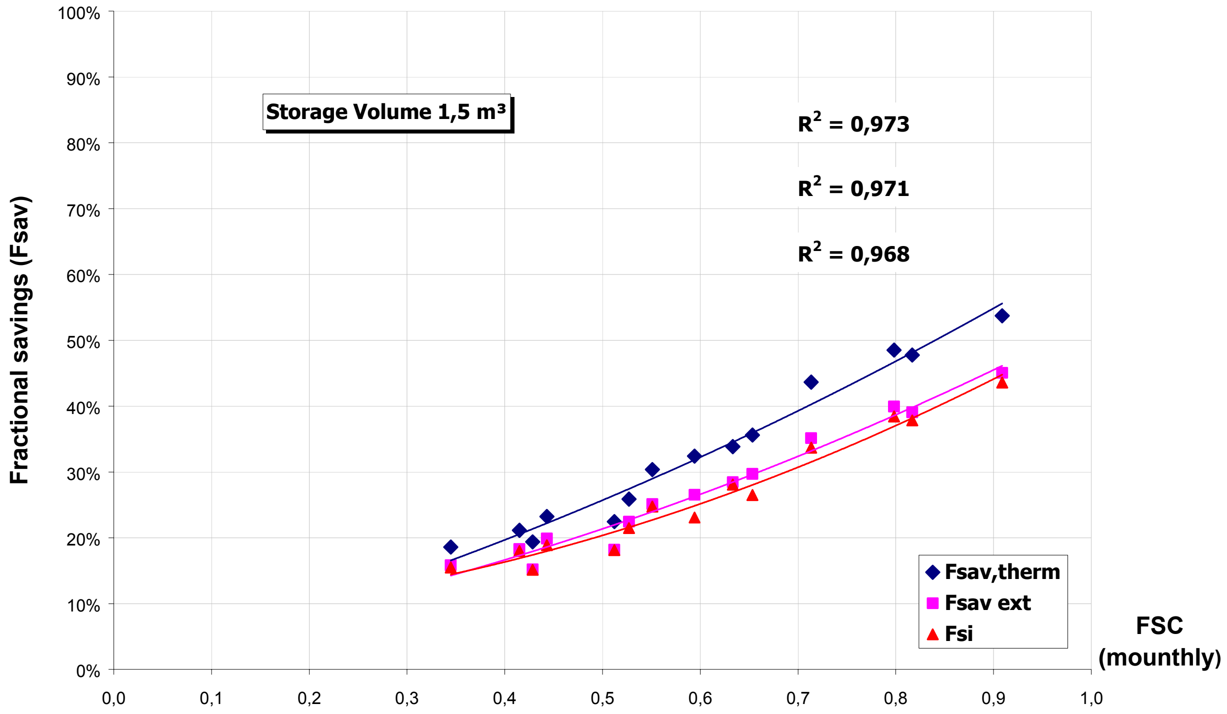


Fig. 35 Fsav,therm, Fsav,ext and FSI as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses with a storage size of 1.5 m³.

In Fig. 35 four different collector areas with 10, 15, 20 and 30 m² aperture area are combined with a 1,5 m³ storage. The calculations had been carried out for Stockholm, Zurich and Carpentras for single-family houses with a heating load of 30, 60 and 100 kWh/(m²a).

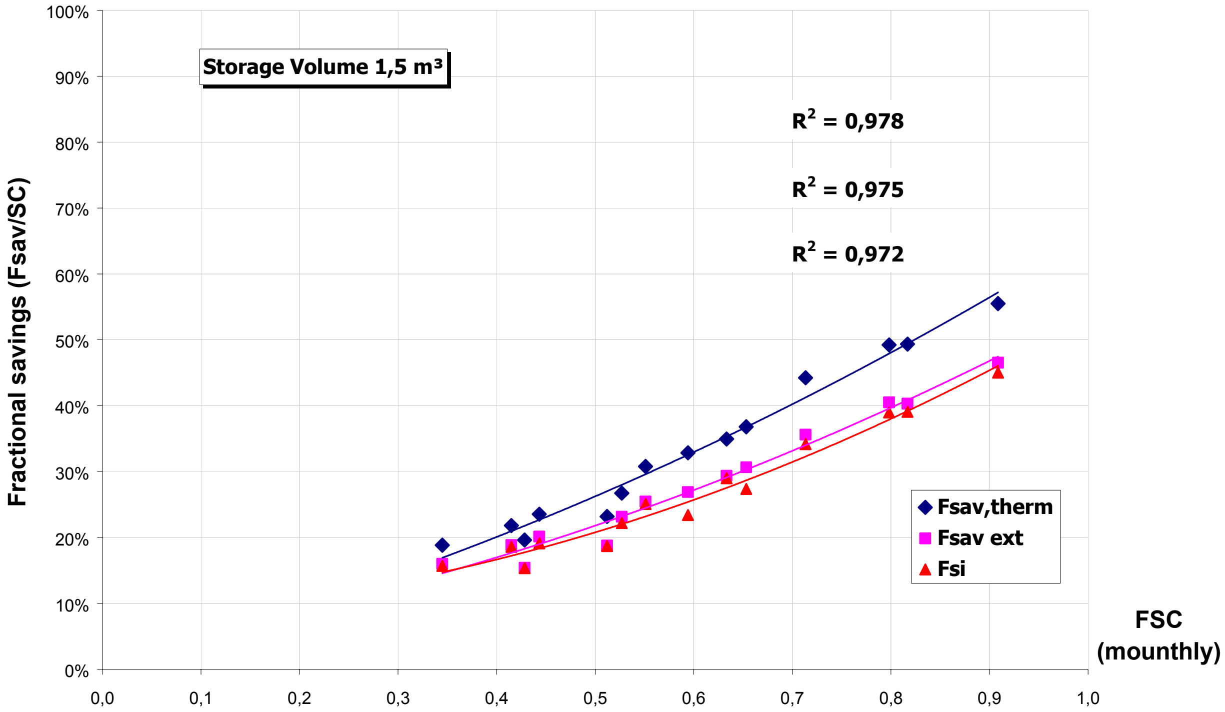


Fig. 36 Fsav,therm, Fsav ext and FSI as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses with a storage size of 1.5 m³. Including a storage capacity correction factor SC.

The data of Fig. 36 correspond to those from Fig. 35. In addition a storage capacity correction factor SC is added.

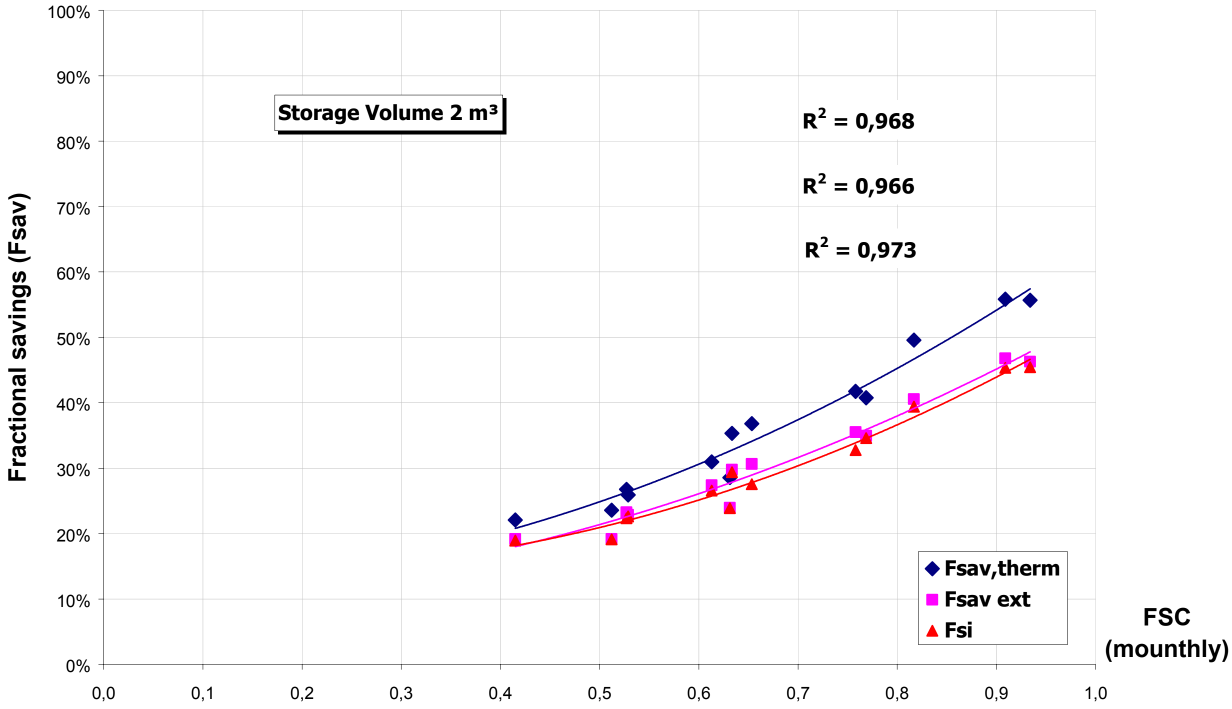


Fig. 37 Fsav,therm, Fsav,ext and FSI as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses with a storage size of 2 m³.

In Fig. 37 four different collector areas with 10, 15, 20 and 30 m² aperture area are combined with a 2 m³ storage. The calculations had been carried out for Stockholm, Zurich and Carpentras and single-family houses with a heating load of 30, 60 and 100 kWh/(m²a).

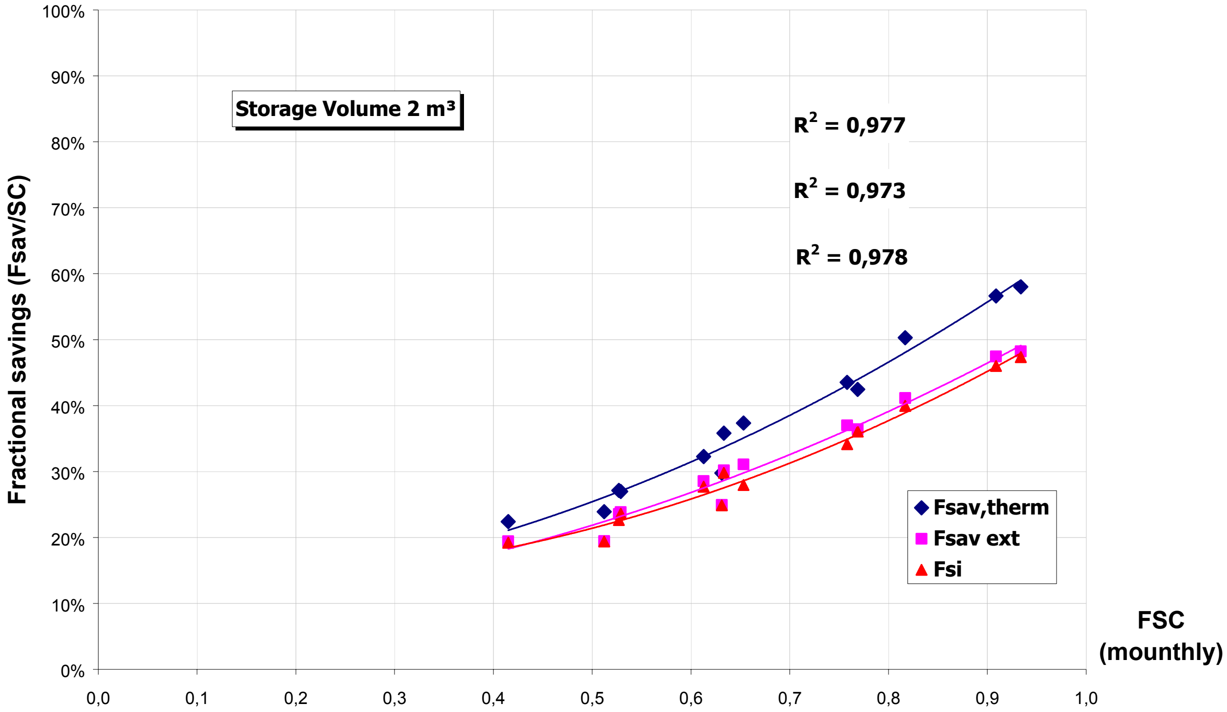


Fig. 38 Fsav,therm, Fsav ext and FSI as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family houses with a storage size of 2 m³. Including a storage capacity correction factor SC.

The data of Fig. 38 correspond with those from Fig. 37. In addition a storage capacity correction factor SC is added.

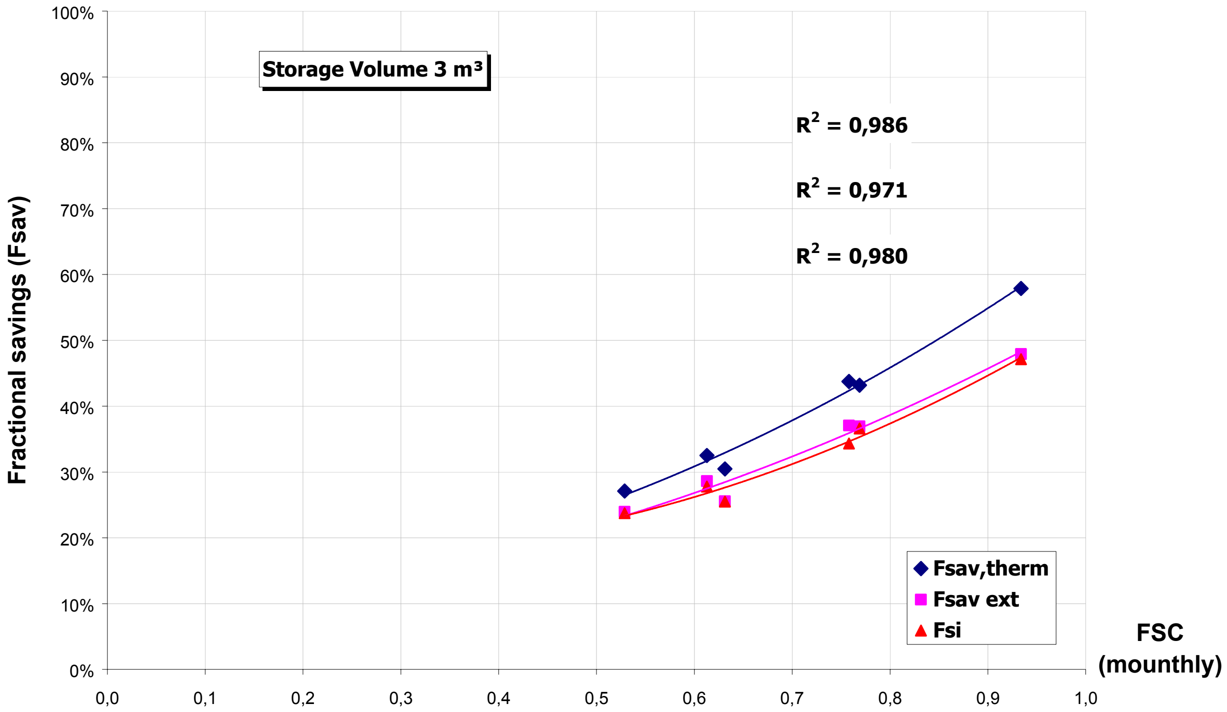


Fig. 39 Fsav,therm, Fsav,ext and FSI as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family house with a storage size of 3 m³.

In Fig. 39 four different collector areas with 10, 15, 20 and 30 m² aperture area are combined with a 3 m³ storage. The calculations had been carried out for Stockholm, Zurich and Carpentras and single-family houses with a space-heating load of 30, 60 and 100 kWh/(m²a).

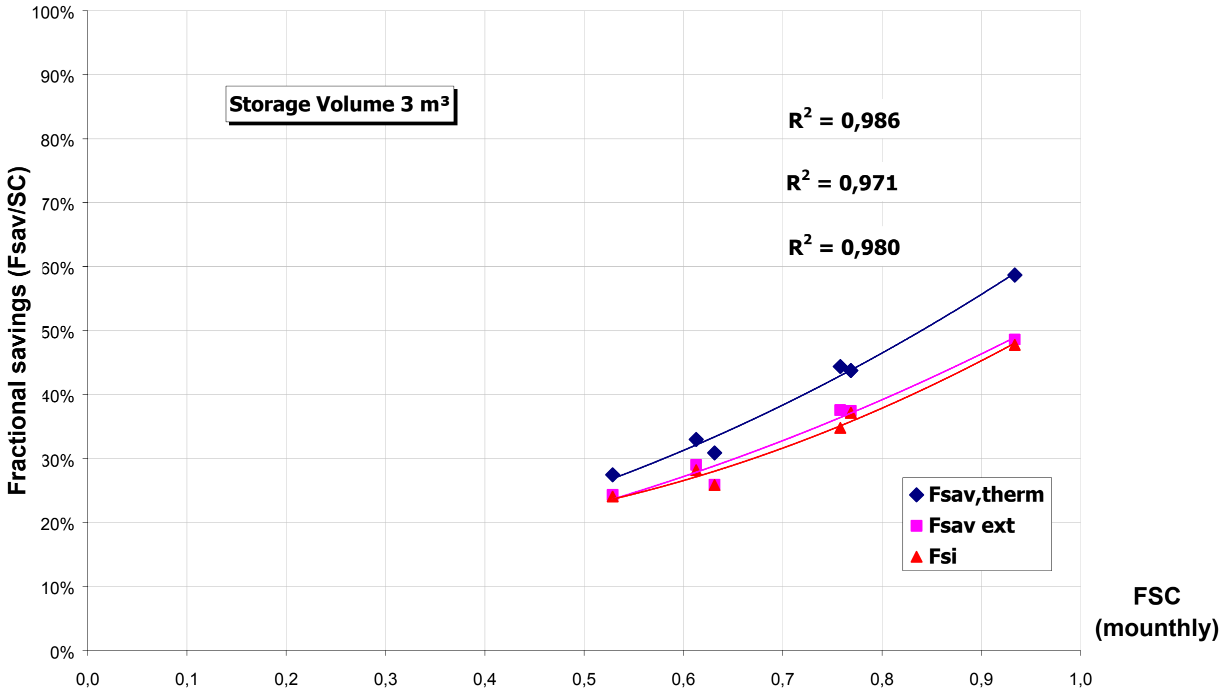


Fig. 40 Fsav,therm, Fsav,ext and FSI as a function of FSC for 3 climates (Stockholm, Zurich, Carpentras) and 3 loads (30, 60, 100 kWh/(m²a)). Calculations for single-family house with a storage size of 3 m³. Including a storage capacity correction factor SC.

The data of Fig. 40 correspond with those from Fig. 39. In addition a storage capacity correction factor SC is added.

6 Lessons learned

6.1 Lessons learned concerning simulation

- The differences between the simulation results using different computers should be taken into consideration. In addition different compilers or compiler settings might result in variations of the results for the same simulation deck. Particularly when working on comparisons, as done within this task, all used types, compilers and compiler settings should be fixed for everyone. The ideal case would have been one person responsible for a common trnlib32.dll, which include all the types needed, also not standard or special ones.
- Due to differences in results between different computers if possible one should use only one machine to simulate a particular system. This decreases simulation inconsistencies and improves the accuracy of the evaluation of a particular system.
- All simulations should be checked according to the energy balances.
- The DHW profile chosen for Task 26 show relatively extreme values, sometimes above 1200 kg/hr. If the simulations does not show significant penalties for DHW, the given system in practice will always meet the load and will deliver a high thermal comfort.
- Between the flow pipe (Type 31) and the Multiport$^+$ Store (Type 147) a convergence promoter (Type 44) had been added to make the simulation converge.
- Due to missing of any immersed heat exchangers and moderate component sizes the simulations worked quite stable.

6.2 Lessons learned concerning System #9b

- Large storage volumes combined with small collector areas lead to relative high thermal losses from the store and decrease the solar fraction. At the same time it increases the use of auxiliary heat.
- The very low set temperatures applied only to the upper third of the store as well as the cold mains water entering the immersed DHW preheating tank at the bottom of the buffer results in very low return temperatures for the solar loop and therefore high efficiency of the solar circuit.
- The efficiency of the solar loop is reinforced by the fact that the auxiliary for the domestic hot water is located outside the buffer, in the external domestic hot water tank. In addition during summer the system works as a “solar-only“ system, because the auxiliary for the space heating is switched off.
- Due to the drainback principle and relatively high flow within the collector the electricity consumption of the system has a large potential for energy savings.
- The system is delivered with a “low efficiency” collector with polymer absorber, which from the costs point of view is favourable. Also not that important for a low temperature system like the SolarNor one, from the efficiency point of view the “low efficiency” collector is a disadvantage.

7 References

[1] Klein S.A et al. (07/1996): TRNSYS 14.2, User Manual. University of Wisconsin Solar Energy Laboratory.

[2] Weiss, W. (ed.) Solar heated houses – A design handbook for solar combisystems, James & James Science Publishers, 2003.

[3] Streicher W., Heimrath R. Structure of the Reference Buildings of Task 26, Technical Report, IEA SHC Task 26 Solar Combisystems, **http://www.iea-shc.org**, 2003

[4] Letz T. Validation and Background Information on the FSC Procedure, Technical Report, IEA SHC Task 26 Solar Combisystems, **http://www.iea-shc.org**, 2002.

[5] Rekstad J., et al. Product descriptions, internal papers, oral information.

[6] Letz, T. Validation and background information on the FSC procedure, Technical Report, IEA SHC Task 26 Solar Combisystems, **http://www.iea-shc.org**, 2003

8 Appendix: Description of Components specific to this System

1 Drück, H. (05/2001) Multiport$^+$ Store - Model for TRNSYS, Type 147
Version 1.21, Institut für Thermodynamik und Wärmetechnik, Universität Stuttgart.
Draft Version of Manual, May 2001.

2 Papillon, P., Achard G. Heating Floor Model, Type 100, Ver. 1.3
dated 08/March/00.
Manual Version 1.2 – 28. Sept. 1999.

Note

Type 147, “Multiport $^+$ Store - Model”

In principle the model is comparable with Type 140 “Multiport Store – Model”
In addition to Type 140 an immersed gas boiler is implemented. For the presented calculations only the features which are also available with Type 140 are used.