Simulation and Optimization Report
- MaxLean Concept -

A Report of IEA Solar Heating and Cooling programme - Task 32

Advanced storage concepts

for solar and low energy buildings

Report of Subtask D

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Task 32
Storage

SOLAR HEATING & COOLING PROGRAMME
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Simulation and Optimization of the MaxLean System

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A technical report, part of Subtask D

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Contents

1 Abstract

This report describes the theoretical examination of an extreme solar combisystem design. The simulations were carried out as part of Task 32, advanced storage concepts for solar and low energy buildings of IEA solar heating and cooling programme. The system concept investigated is suitable for thorough cost reduction: It may have a light, non-pressurized tank, consists of few components and uses simple controls. It can easily be integrated into the heating system of an existing house with water-based central heating. It is called the MaxLean system because the authors reckon that it is as lean as a solar combisystem can get in terms of simplicity and material use. Fig. 1 (page 6) shows the hydraulic scheme of the MaxLean system. Its distinctive features are:

- <u>A drain back collector loop.</u> A low flow rate was used. It was assumed that the heat transfer medium is water and that the collector loop is non-pressurized in no-flow conditions (due to a non pressurized tank which acts as the drain-back vessel). Consequently the collector operation is restricted to temperatures below 100℃. It is assumed that the pressure in the collectors is built up and sustained above 1 bar during collector loop operation (by means of an adequate pump and a pressure reducing valve at the end of the collector supply line) to avoid the building up of steam and cavitation. A perfect stratifier is assumed at the solar loop inlet to the tank.

- <u>A simple integration of the auxiliary heater into the system.</u> The auxiliary heater (a condensing gas boiler was assumed) is directly attached to the tank. The set supply temperature is invariable (63℃). Boiler operation is determined by measuring the temperature at an appropriate level in the tank. This connection and interaction of the boiler with the combitank is beneficial because it is simple to install and configure. It is disadvantageous because – in this most simple configuration – possible gains due to boiler modulation are disregarded. (More sophisticated boiler controls could increase boiler efficiency by optimizing boiler modulation. This was not simulated.)

- <u>A direct connection of the space heating loop to the tank.</u> There is a thermostatic mixing valve with a fixed set temperature (50℃) and a variation of the volume flow rate (through the radiators or the heating floor) to modulate space heating (DFFC, direct feed flow controlled) instead of the common flow temperature modulation with a mixing valve and a variable set temperature according to a heating curve. A perfect stratifier was assumed at the inlet of the space heating return to the tank.

The energy performance of the MaxLean system was compared to a “solar reference system” which is sought to represent the state-of-the-art of solar combisystem technology. The reference system was derived from the common Task 32 base case system, described in detail in “the reference heating system, the “template solar system” [1]. The collector area was set to 20 m^2 and the store volume to 800 l: Some modifications were made to the original solar template system for it to serve as the starting point for the simulation study: The efficiency of the heat exchanger for domestic hot water heating was reduced to a typical value and some important criteria (the port positions of the space heating return; the boiler power; the set temperature of the auxiliary boiler; the position of temperature sensors in the tank; the collector loop specific flow rate; the dead band of the solar loop control), were optimized to achieve the best energy performance for one particular load and climate (the 60 kWh/a per m^2 floor area house [1]; the task standard domestic hot water consumption of 3000 kWh/a; Zürich).

The reference simulation system was then transformed in steps towards the MaxLean system concept. Subsequently the MaxLean system was optimized using the same procedure and criteria, which were previously used to optimize the solar reference system. The same features were optimized and the same load and climate was used to perform the optimization.

The result of the simulations show, that the MaxLean system concept reduces the auxiliary energy consumption (natural gas) from 8544 kWh (optimized solar reference) to 8162 kWh/a

(optimized MaxLean). The reduction of energy consumption is 382 kWh/a, or 4.5%). Nearly half of these savings (170 kWh/a, 2%) are due to the space heating loop with fixed flow temperature, and flow control (DFFC).
The simulation study confirms results from earlier work [9]. It reveals that a thorough simplification of solar combisystems is not only a possibility for major cost reduction but may also significantly enhance solar energy performance.
Also, an optimization of the store volume and the collector area based on economical and ecological criteria is explored. The method applied and the results obtained are described.

2 General description of MaxLean system

2.1 Main features

The so called MaxLean system is a hypothetical system. The data and results presented are based on assumptions and simulation. The results are fully dependent on the assumptions made (e.g. the thickness and conductivity of the store insulation). The simulated system could be built with components readily available on the market (with the exception of some specific controller functions, which would be easy to implement). Even though several solar combisystems incorporating features of the MaxLean system concept[1] are available on the market, none of them include all the features of the MaxLean concept. These features are described below. In chapter 3.2.1, general aspects are described. In chapters 3.2.2 – 3.2.8 the characteristics of each charging and discharging loop are explained. The parameter settings chosen are listed also in chapter 3.2.1.

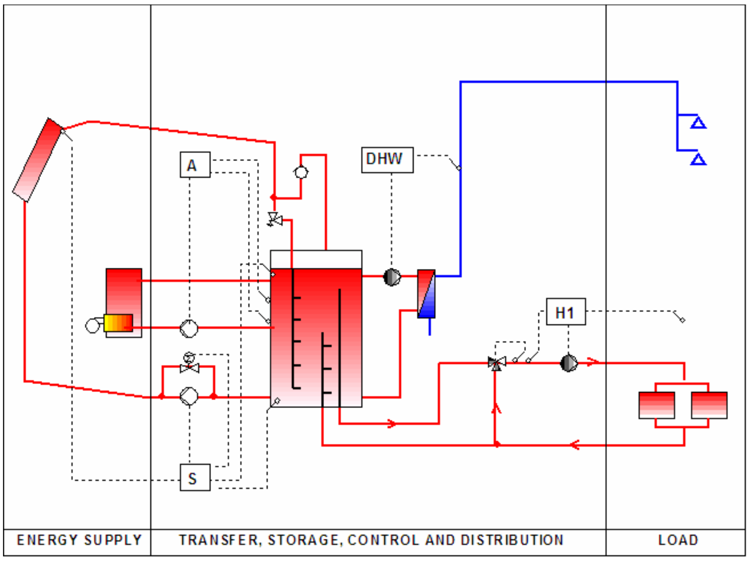


Figure 1: Hydraulic scheme of the MaxLean system

2.2 Requirements for future solar combisystems in one-family houses and the MaxLean system

The most common solar combisystems are relatively small. NEGST [2] reported typical sizes between 5 m^2 (in The Netherlands) and 18 m^2 (in Austria, respectively 20 m^2 for the special Norwegian systems). A separate optimization study summarized in chapter 6.2 and described in detail in the diploma thesis “Simulations of innovative storage concepts” [3] revealed a most economical system size for the base case used in this study[2] of only about 0.7 m^3 of store volume and 10 m^2 of solar collectors. If solar thermal energy shall play an important role in the energy economy or for high solar fractions (more than 50%) as suggested in “Solar Thermal Vision 2030” [4], larger systems with high storage capacity are required. This implies collector areas will also be large. With the increasing energy-efficiency of buildings however, solar energy will cover a relatively small heat load and the specific system gains (the solar energy utilized per system size) shall be relatively small. Therefore, the amount of material used shall be kept low in order to limit the cost, the embodied energy implied and the indirect environmental impact caused by material use. The concept investigated in this study is called the MaxLean system, because the components and material used is reduced as much as (probably) possible. This section will explain that the concept thoroughly suits the requirements of future solar thermal energy utilization in houses. Several consequences result from the assumption of relatively small specific solar yield:

[1] The system offered as SolarPur by Consolar (www.consolar.de), Solaris by ROTEX (www.rotex.de) and the Solarnor concept (www.solarnor.com) all have non-pressurized tanks and a drainback collector loop which is directly connected to the storage tank. The heat transfer fluid in the collector loop is also the heat storage medium. The tank also takes over the function of the drainback vessel. In the case of the Solarnor system, the space heating (usually a radiant floor) is directly connected to the tank. Also, if the heating device is suited, the auxiliary heater is connected to the tank directly without any heat exchanger. Rotex' and Consolar's tanks are made of polymer material, the standard design tank of the Solarnor system is made of stainless steel.

[2] Location: Zürich; specific annual heat demand: 60 kWh/m^2; annual space heating load: 8485 kWh

- In future applications, the collector area per installation is likely to be large, with the following consequences:
  - The total effort for the installation of the collector loop is relatively large. As a consequence the extra effort and restrictions associated with the drainback technology are less relevant.
  - The duration of collector loop stagnation (shut down of solar energy collection because the store is fully charged) is extended, which calls for a technology which safely avoids durability problems caused by stagnation.
  - If separate fluids for heat collection and heat storage are used, the solar loop heat exchanger has to be large to fit in with the expanded collector area. The elimination of the heat exchanger is more beneficial.

The phenomena mentioned above voice in favour of the drainback technology for the collector loop. The MaxLean system concept does without solar loop heat exchanger or drainback vessel. To cut down on material use is one of the core features of the MaxLean systems. The store itself is the most important component in this respect. This will be explained in the next section.

2.3 Modularity and material use

Because there is a large quantity of storage material, it must be inexpensive and ecologically sound. The core of the MaxLean system is a simple water tank which can be non-pressurized. Therefore it may have thin walls or flat walls. The walls may be made of plastics which, because less material is required, need not be inexpensive. It can also be a long lasting material such as stainless steel. Its walls potentially being flat, the tank is particularly well suited for insulation with vacuum panels. If the tank is non-pressurized it may be vented or closed. If it is closed, there will have to be provision to allow for the temperature induced expansion of the water (plus air or gas for the drainback function). Even though a non-pressurized tank seems to be the logical solution, there is no technical problem in using a pressurized tank instead. A reasonable compromise might be a store which is closed and may be moderately pressurized. Another possibility to be considered is a closed non-pressurized store and expansion implemented with a hydraulically communicating simple flexible vessel such as an impermeable bag. The “flexible vessel” could be connected to the top of the tank and contain air or gas only. Or it could be connected to the bottom of the tank (but located above the water level). It could also be located clearly above the tank to solicit the tank to a moderate but sharply defined pressure.

- To fit the system to the large variety of situations caused by the different space heating loads, climates and budgets and achieve reasonable production quantities, the system concept shall be well suited for modular design:
  - The MaxLean concept is based on a simple store design and separate components at its periphery which are connected to the store by independent hydraulic circuits, as e.g. the auxiliary heater. There are no heat exchangers built into the store (with the exception, perhaps, of the domestic hot water heating, which could be achieved with any of the methods common with solar combistores).
  - The tank being inexpensive, it could be duplicated or multiplied and connected in parallel to adapt the storage capacity to specific conditions and needs.
  - If the storage tank is non-pressurized, it may be of rectangular shape with flat walls. Several tanks can be placed adjacent to one another. They could be insulated together.
  - If there are thin storage walls, the tank is light and easy to transport for installation.

With an ecologically sound and inexpensive storage concept suited for high solar fraction, the MaxLean system might bridge the gap between the usual small individual solar combisystem in single family houses and the large collective solar combisystems with seasonal storage.

2.4 Auxiliary heating and technical integration

However optimistic the scenarios for future solar thermal energy utilization may be, it is safe to assume that, in the medium term, solar fractions will rarely come close to 100%. Therefore solar combisystems must be well suited for the integration of and the interaction with an auxiliary heater. The types of auxiliary heaters the system should be well suited to be combined with are:

- Heat pumps with their difficulties to achieve the temperatures necessary for hot water production: In combination with the MaxLean concept, heat pumps may achieve a sufficiently high outlet temperature (for domestic hot water preparation), because there is direct charging without an extra heat-exchange. Moreover, a high temperature lift contributes to high outlet temperatures. To achieve this important characteristic, the flow rate of the auxiliary heater should be adapted to heat the water to the desired temperature in one go-around. This is relatively easy to achieve if the auxiliary loop is fully independent of the space- and hot water heating. Together with high stratification, the average temperature of the auxiliary loop is kept low for high efficiency.
- Condensing boilers which require low return temperature for high efficiency: Low return temperatures are possible with good stratification in the tank. As in the case of heat pumps, the possibility to adjust the flow in the auxiliary loop is important.
- Wood boilers which require a sufficient storage capacity: Some storage capacity is also beneficial for pellets and other heavy boilers. It cuts the numbers of on-off cycles which increases the boiler’s efficiency and reduces its emissions.
- Any existing auxiliary heater: In many cases, an existing heating device stays in place when solar heating is installed. The system concept should allow for easy integration of virtually any existing boiler with the solar energy system. The hydraulic connection should be simple and clear. The control of the auxiliary heater and the (new) control strategy of the auxiliary heater and its (old) controller should be equally simple.

In the next sections the principles of each circuit for charging and discharging of energy are described. It is explained how the MaxLean system responds to the requirements outlined above.

2.5 Charging and removing heat from the storage tank of the MaxLean system

2.5.1 The collector loop

The collector loop is directly connected to the storage tank, such that the fluid in the collector loop may be water. When the collector loop is not in operation, the water drains back into the storage tank. Freezing is avoided but the pipes must be installed with a slight inclination. (A good description of the drainback technology is given by Huib Visser and Markus Peter in: “Solar heating systems for houses, a design handbook for solar combisystems” [5]. There is no need for a solar loop heat exchanger and the tank itself is also the drainback vessel. The solar loop pump fills the system whenever it switches on. If the system height (the difference in altitude between the tank and the topmost point of the solar loop) is high then the pressure head of the pump must be at least as high, which could be achieved through use of a volumetric pump. In this case there has to be a bypass valve across the pump as indicated in figure 1 to drain the collectors. Air from the top of the tank enters the supply line through the check valve shown above the tank in figure 1. In the place of the valve a rising pipe could be used as has been demonstrated in “Installations solaires combines pour villas : optimisation eau chaude, chauffage et climatisation” [6].
In the simulations there is a constant flow rate in the collector loop. If the tank is non-pressurized, the pump operation must cease if the temperature of the fluid entering the tank

approaches 100℃. This limit was respected in the simulations. In a practical set-up, a pressure reduction valve has to sustain the pressure built up by the pump in the collector loop. In this way, the pressure in the collector loop is above the boiling point during pump operation even if the collectors are located above the tank. In practice the pressure sustaining valve could be a thermostatic valve to reduce the power consumption of the pump. In the simulations it was assumed that the electrical power consumption of the solar loop pump is the same as in the solar template system. This should be accounted for when interpreting the simulation results. However, the power consumption assumed for the pump of the MaxLean system is realistic. Also it is assumed that the inlet flow enters the tank through a stratification device which perfectly directs the incoming water to the level in the tank with the same temperature. In an experimental study a specially designed inexpensive stratifier had been investigated for use in the MaxLean system. The design simply consists of parallel plates at appropriate spacing. This device is particularly suitable if the flow rate through the inlet port is low. If at least one tank wall is flat, the wall could act as one of the plates. The experiments are described in a presentation which includes films [7] and a Task 32 technical report [8].

2.5.2 The auxiliary loop

The auxiliary heater loop is connected separately and directly to the tank. It is hydraulically independent from all other connections and circuits. It may be controlled separately, which is an important feature for the practical system integration (see also the explanation in chapter 1.4 about auxiliary heating and technical integration, above). Due to this, the control strategy of the auxiliary heater can be chosen to best fit the particular heater and situation. In the simulations it was assumed that the auxiliary heater – a condensing gas boiler – raises the temperature by 10 K in every pass through the heater. This strategy was chosen, because it is the strategy used in the task 32 solar template system. This is far from being the best possible strategy if a condensing gas boiler is used. In a previous study [9], a better strategy had been investigated by simulation: The auxiliary heater's set supply temperature is invariable. When the auxiliary heater is switched on, it supplies water at a set temperature to the top (or nearly the top) of the tank. This (set) temperature should suffice for hot water preparation. This control strategy is relatively easy to implement if a new solar combisystem has to be combined with an existing auxiliary heater. In the simulations documented in this report the recommended condensing gas boiler model for simulations in IEA SH&C Task 32 was assumed. Regarding the control criteria for switching the auxiliary heater on or off, there is a variety of possibilities:

- In the simulations of the MaxLean system – as in the solar template simulation system of task 32 – the operation of the auxiliary heater loop is controlled by two sensors. The boiler and pump are switched on if the temperature of the water in the storage tank drops below a certain minimum temperature (47 degrees) at the upper sensor and switched off if the temperature at the lower sensor exceeds a certain maximum (55 degrees).
- In a presumably more advantageous strategy, the two sensors would trigger auxiliary heating for the two separate purposes of space- or water heating: The heater is activated if the temperature at the upper sensor position indicates a need to store heat to be ready for hot water preparation or if the temperature at the lower sensor position is insufficient to cover the actual space heating load. With this strategy, the auxiliary heater does not have to operate if the space heat requirement can be covered by solar energy alone. This strategy was simulated in earlier simulation work [9]. The upper sensor is positioned to make sure that the energy and temperature in the top of the store is sufficient for hot water comfort. The lower sensor is positioned below the outlet to the space heating loop. The storage volume between the lower sensor and the outlet should be chosen (or adapted) to limit the cycling (the number of times the heater switches on or off). The temperatures measured by both sensors could be used to decide about switching the heater off: When the temperature at either one of the sensors is below the maximum requirement, auxiliary heating may

continue (in case of a condensing gas boiler preferably at a reduced heating rate for high efficiency). Heater operation shall cease when the temperatures at both sensors are at or above their upper limit.

- In a practical design the auxiliary loop could operate on one sensor only. In this case the sensor would be positioned at or just below the outlet to the space heating loop. This control strategy is easy to implement with virtually any auxiliary heater controller. The simulations carried out by Poretti suggest that this simple strategy might only marginally reduce the systems efficiency as compared to the strategy using two sensors as described above.

In any case, for high efficiency and performance, it must be ascertained that the flow rate in the auxiliary loop fits in with the auxiliary heater power. To achieve this, the flow rate through the auxiliary loop may be adjusted to a suitable but invariable value. This most simple choice was assumed for the simulations. In many practical applications the design (maximum assumed) space heating load is around 5 kW but the gas boiler may modulate in a power range well above (e.g. between 3 kW and 30 kW). In such a case the maximum heating power of the gas boiler could be limited to about 6 kW. The flow rate has to be throttled accordingly. If possible, the controller settings of the heater would equally be adjusted to limit the heating rate. Thus the boiler would always work at a relatively low heating rate and high efficiency.

It would, however, be even better to vary the flow rate through the auxiliary loop. It could be varied by means of a variable speed pump, a thermostatic valve or a motorized valve. Particularly if the auxiliary heater power is variable, as is the case with state-of-the-art modulating gas boilers, a variable flow rate in the auxiliary loop could be advantageous. With an adapted boiler or heat pump design, the flow could be driven by natural convection. In this case the heating power of the boiler would adapt to the flow rate and the flow rate would adjust depending on the tank temperature. In this way the auxiliary loop power and flow rate could be adapted according to the heat requirement at any time.

In all the control strategies described above the auxiliary heater is put into operation when it is necessary to cover the load (whenever the temperature in the tank is crucially low), by means of a simple “run” signal. There is no other exchange of information between the auxiliary heater controller and the solar system controller. If the heater modulates, it adjusts its power to meet the set outlet temperature with its own controller and sensor.

In a more complex control strategy, the power setting of the auxiliary heater (or the flow rate of the auxiliary loop) could be made dependent not only on the temperature at the outlet of the heater, but also on the temperature (or the rate of temperature change) measured by the sensor(s) in the tank.

Connecting the auxiliary loop directly to the tank has several advantages. However, in practice, a possible restriction must be accounted for: If the auxiliary heater is not designed to be used in open circuits (with renewal of oxygen and consequently corrosion), the tank will have to be a closed design or the auxiliary heater loop has to include a heat exchanger for heat transfer.

2.5.3 The space heating loop

In the simulations the return flow of the space heating loop is directed to the tank via a stratification device (or “stratifier”). As in the case of the flow from the solar collectors, the computer model assumes perfect stratification within the specified extension of the stratifier (between the height of the inlet and outlet ports). The water is taken directly from the tank at a specific height to be supplied to the heat distribution system (in practice to radiators or to a radiant floor). There is a mixing valve to limit the flow temperature to 50°C. This temperature was chosen because this is often the maximum temperature permitted in the case of floor heating. In the simulations the temperature available at the respective position in the tank virtually always exceeds 50°C. The supply temperature after the mixing valve is 50°C whenever space heating is required. An earlier simulation study had revealed that the mixing valve’s diminishing effect on the system efficiency is negligible (see [9], fig. 9-43, p. 70). (The reason for this was not investigated. Presumably, if the flow and the return temperature is low the detrimental effect of mixing (and slightly raising the return temperature) is not severe. However, care should be taken in generalising this hypothesis: The effect of mixing the flow to the radiators might depend on the size (the heat transfer capacity rate) of the heating system (radiators or heating floor), which was assumed to be rather high in the simulations. In general, there are two ways to vary the energy delivery for the heating of a building: By variation of the supply temperature or by variation of the mass flow. In practice, usually most heating concepts combine these two by adapting the supply temperature to the ambient temperature on the one hand and by using thermostatic valves which adapt the flow rate of the respective radiator or radiant floor section on the other hand. In this study, the energy supply to the radiators was controlled by modulation of the flow rate in the heat distribution system. It was assumed that there is no short-circuiting but well balanced flow distribution in parallel sections of the space heat distribution system. Balancing of the heat distribution system is always important when the performance of the heating system depends on the return temperature. In case of the MaxLean system it is safe to assume that balanced circuits are particularly important.

The flow rate could be adjusted according to the ambient temperature, the room temperature or the temperature of the return (or in any combination of these options). The possibility to use the return temperature for flow modulation might be an important feature: If no thermostatic valves are used and the heat transfer capacity rate is high (both are typical for floor heating) the return temperature depends on the room temperature and the influence of the room temperature can be considered. This feature and its benefits were studied in [10]. In the simulations of the MaxLean system, the flow rate varied to meet a given heat demand which was known from a load file. The flow control strategy, called DFFC (Direct Feed Flow Control), is different from the current practice. In this theoretical investigation, the DFFC strategy enhanced the system performance. The higher supply temperature leads to a low flow rate and a low return temperature. Consequently there is better stratification in the tank, which improves the efficiency of both the auxiliary gas heater and the solar collectors. Earlier simulation work, which used a different (presumably a better) gas boiler simulation model [11] suggested, that the DFFC concept reduces gas consumption by 2.4% ([9], p. 91). (In this study, the reduction is 2%, see section results on p. 28). According to Poretti ([9], table 10-1, p. 91), approximately half of this reduction is due to a higher solar gain, the other half is due to a higher boiler efficiency. However, the DFFC is just one – unusual – specific feature, of the MaxLean system concept, which any manufacturer may decide to adopt, reject or consider later. The same statement applies for the open and non-pressurized space heating loop: The simulation study reported in [9] quantified the effect of a (with 2m^2 moderately sized) immersed heat exchanger to – inexpensively – enable a closed, pressurized space heating loop. In that case the additional heat exchanger reduced the system performance by 2.2% (increase of the auxiliary consumption, see [9], p. 103). The possibility of a closed non-pressurized (or a closed, slightly pressurized) tank and space heating loop also exists: This is not complicated to put in practice and might be a pragmatic compromise, because many heating systems (most radiators and many boilers and most pipes) do not withstand the corrosive effect of an open loop. In this study, different (various differently sized) heat distribution systems were simulated in different houses and climates according to the pattern agreed upon in the project. However, the study did not focus on the influence of the heat distribution system's characteristic. The question was addressed in earlier work, where it was found that DFFC works well in a house with a less powerful space heating system (e. g. fewer or smaller radiators, less heating floor area; see [9], fig. 10-5, p. 92: with the DFFC the heat transfer capacity rate of the heat distribution system can be reduced by one third to result in the same gas consumption as the reference case).

2.5.4 Hot water preparation

In the simulations of the MaxLean system the hot water was prepared with the same concept as in the simulations of the task 32 solar template system: instantaneous water heating by means of a heat exchanger. The same components (including the controller) were used.

However, the heat transfer rate of the heat exchanger was slightly reduced. The concept of instantaneous water heating via a heat exchanger with a high heat transfer rate leads to high stratification and consequently high solar gains, which are not representative. The average combistore is likely to either have:

- a less favourable control method of the instantaneous water heating or
- an internal heat exchanger or
- an integrated hot water heater store (tank-in-tank design).

Any off these concepts for hot water preparation might be used in combination with the MaxLean system concept. Draw-off induced stratification is therefore suspected to be lower in the store of the MaxLean system than in the solar template simulation system. To simulate a representative situation the heat transfer rate was reduced.

3 Modelling of the system

3.1 TRNSYS model

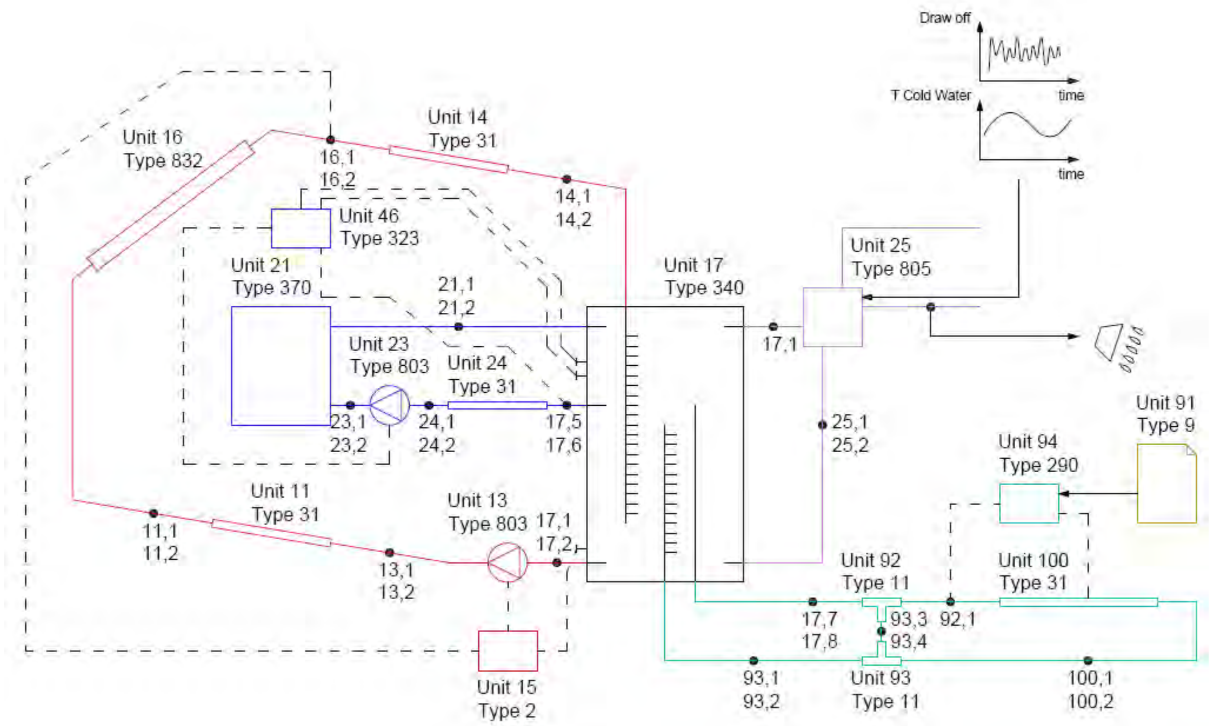


Figure 2: Modelling of the MaxLean system in TRNSYS

3.2 Definition of the components included in the system and standard inputs data

3.2.1 General settings

Main	
Mai	
simulation time step	[a]1/20 h
tolerance integration / convergences	[a]0.003 / 0.003
length of simulation	[a]13 months
climate	[b]Zurich
building	[b]SFH60

Table 1: General settings

3.2.2 Collector loop

The collector loop is a drainback system with water filled collector array taking the water directly from the tank. There is no heat exchanger between the storage tank and the solar collector. The collectors are driven in low-flow mode.
The collector area of 20 m^2 selected for the base case is an arbitrary choice made before the economic dimensioning were carried out.

[a] Values according to the template solar system
[b] Base Case (BC)

Collector	
type	flat plate selective (ref)
aperture area	20 m^2
tilt angle	45°
azimuth (0° = south, 90° = west, -90° = east)	0° (= south)
specific mass flow rate	10.2 kg/m^2-h
upper/lower dead band (switch on / off)	7 K / 3.3 K
cut-off temperature of collector	100 °C
fluid specific heat	[a]4.19 kJ/kg-K
η_0	[a]0.8 -
a_1	[a]3.5 W/m^2-K
a_2	[a]0.015 W/m^2-K^2
inc. angle modifier (50°)	[a]0.9 -
Pipes between collector and store	
total length	15.00 m
inner diameter	0.012 m
insulation thickness	0.054 m
thermal conductivity	0.042 W/m-K

Table 2: Settings of collector loop

3.2.3 Store

The tank has a volume of 800 litres in the base case. For the simulation study in addition to the fixed volume a specific volume was calculated with a ratio of 0.07 m^3/m^2. The relative heights of in- and outlets to the store and positions of the temperature sensors are calculated dependent to the storage volume according the formulas in table 4 and 5.

Store	
total volume	[b]0.8 m^3
height	[b]1.91 m
store volume for auxiliary	[b]0.287 m^3
number of nodes	[b]39
fluid specific heat	[a]4.19 kJ/kg-K
insulation thickness, thermal conductivity	[a]15 cm, 0.04 W/m-K

Table 3: Settings of the storage tank for the BC

Doubleport description	***Relative height***	***Value(s)***	***Dp Nr.***
inlet of collector loop (stratified)	$=0.84-\frac{1.5}{N_{\max}}$	[b]0.80	1
outlet of collector loop	$=\frac{25}{1000*V_{Store}}$	[b]0.03	1
inlet of auxiliary heating	$=0.92-\frac{1.5}{N_{\max}}$	[b]0.88	3
outlet of auxiliary heating	[a] $=1-\frac{V_{aux}}{V_{Store}}$	[b]0.62	3
inlet of DHW loop	[a] $=\frac{0.5}{N_{\max}}$	[b]0.01	5
outlet of DHW loop	[a] $=1-\frac{0.5}{N_{\max}}$	[b]0.99	5

[a] Values according to the template solar system
[b] BC

inlet of space heating loop (stratified)	0	0.00	4
outlet of space heating loop	$=1-0.5\frac{V_{aux}}{V_{Store}}+\frac{1.5}{N_{max}}+0.09$	[b]0.77	4

Table 4: Relative heights of store doubleports

Sensor description	***Relative height***	***Value(s)***
collector control temperature	$=\frac{50}{1000*V_{Store}}$	[b]0.06
storage protection temperature	[a] $=1-\frac{0.5}{N_{max}}$	[b]0.99
first auxiliary On/Off temperature	$=1-\frac{V_{aux}}{V_{Store}}+\frac{2.5}{N_{store}}$	[b]0.68
second auxiliary On/Off temperature	$=1-\frac{V_{aux}}{V_{Store}}+\frac{2.5}{N_{store}}+\frac{50}{1000*V_{Store}}$	[b]0.75

Table 5: Relative heights of store temperature sensors

V_{Store} [m^3] Storage volume
V_{aux} [m^3] Auxiliary heated volume in store
N_{max} [-] Number of nodes in store

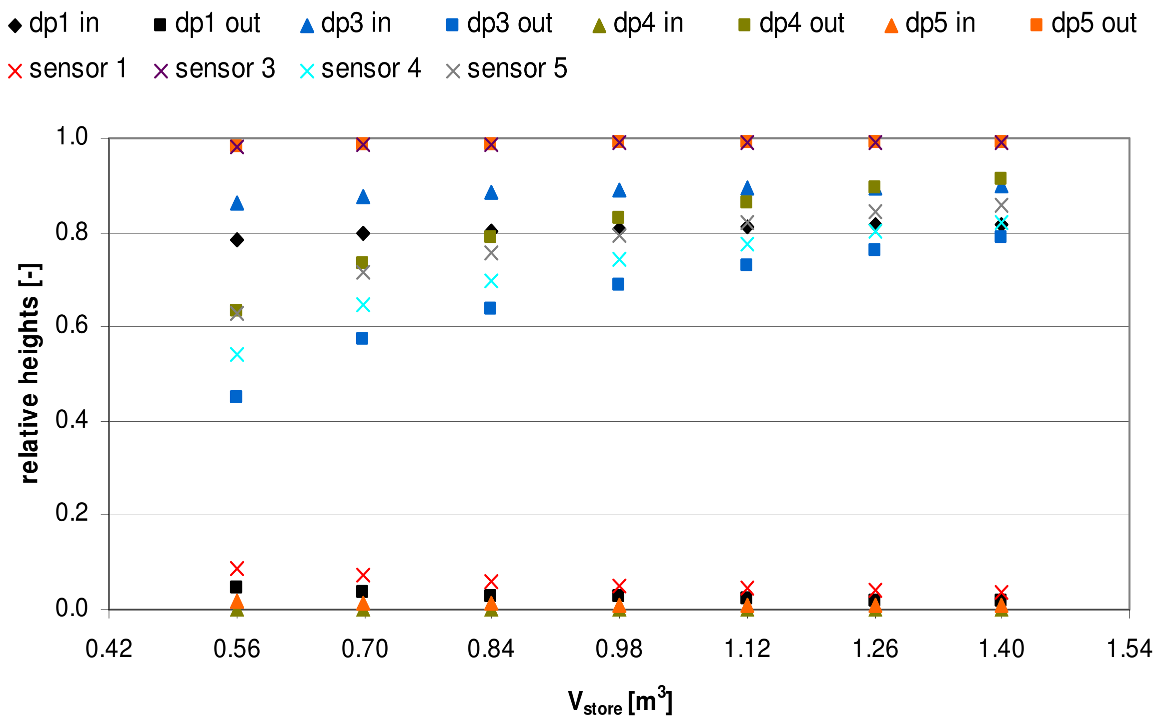


Figure 3: Relative heights of store doubleports and sensors for different volumes of the store

3.2.4 Auxiliary

Auxiliary	
nominal power of auxiliary	[b]22000 kJ/h
set temperature auxiliary into store	[b]57 °C
lower hysteresis limit burner temperature	10 K
design mass flow of auxiliary heater	[b]525 kg/h

Table 6: Settings of the auxiliary boiler

[a] Values according to the template solar system
[b] BC

3.2.5 Building

The building is replaced by Type 9 data reader which reads the load file. The load files for the different climates and houses were generated with the RefBui_v45 system in 3 min time steps. The values for tolerance integration and convergence were both set in accordance to the system simulation to 0.003.
With the reference building simulation the radiators do cover the required heating load in every time step so that no penalties occur for not meeting the room temperature of 20 °C. The radiator power transmitted in the RefBui_v45 system was used to define the space heating load. It was assumed that the room temperatures are the same as the ones in the reference building simulation in case of identical transferred heating power.

3.2.6 Heat distribution

The heat is transferred via a pipe that was fitted to transfer the same energy as the radiator of the template solar system.

Nr.	Description	Value(s)
1	inner diameter of the pipe	0.015 m
2	length of the pipe	151 m
3	heat transfer coefficient for thermal losses to the environment	[3]U_{pipe}
4	density of the fluid	[a]998 kg/m³
5	specific heat of the fluid	[a]4.190 kJ/kg-K
6	initial temperature	[b]50 °C

Table 7: Settings of the space heating pipe simulating a radiant floor or radiators

Climate	Building	$U_{pipe,n}$ [kJ/h.m^2.K]
Stockholm	SFH15	81.59
	SFH30	133.533
	SFH60	143.161
	SFH100	101.91
Zurich	SFH15	65.538
	SFH30	107.218
	SFH60	115.447
	SFH100	82.367
Barcelona	SFH15	58.497
	SFH30	94.664
	SFH60	101.751
	SFH100	73.538
Madrid	SFH15	43.862
	SFH30	74.284
	SFH60	79.029
	SFH100	57.556

Table 8: Climate and building related factors of the heating system

The mass flow of the space heating loop is calculated by Type 290. The electricity demand of a space heating pump is set to a constant value and integrated over the time with an mass flow bigger than 1 kg/h.

[3] see table 7
[a] Values according to the template solar system
[b] BC

3.2.7 Control strategy

For overheat protection the cut-off temperature for the collector loop is 90 °C in the store. The auxiliary heater delivers a temperature rise of 10 K with a maximum of 57 °C (in the BC). The heat distribution system is controlled with the non-standard Type 290. This controller reads the needed heating power from a loadfile and calculates the mass flow to deliver the same heating power (with a certain supply temperature) via a pipe modelled with the Type 31 (pipe or duct). The performance of the radiators is due to the radiator exponent not linear. To get a good set point tracing of the transferred heating power via the pipe, a readjustment was implemented that arises or lowers the needed heating power of a certain time step, if the transferred heating power of the previous time step did not coincides to the last time step.

Nr.	Description	Value(s)
1	length of the space heating pipe	l_{pipe} = 151 [m]
2	diameter of the space heating pipe	d_{pipe} = 0.015 [m]
3	loss coefficient of the space heating pipe	U_{pipe} (see 2.2.6)
4	heat capacity of the fluid	$cp_{,wat}$
5	maximum flow rate	[b]1000 [kg/h]
6	accuracy	0.01 [-]
7	increment	0.1 [-]

Table 9: Parameters of Type 290

Nr.	Description	Value(s)
1	room temperature	output from the Loadfile [°C]
2	supply temperature	output from Tee-piece (mixer); Unit 92, Type 11
3	needed heating power	output from Loadfile [W]
4	ambient temperature	output from Loadfile [°C]

Table 10: Inputs of Type 290

3.2.8 Draw-off loop

The overall heat transfer coefficient of the heat exchanger has been set to a value which results in a return temperature of 17 °C to the store in the case of 10 °C cold water temperature, 60 °C temperature from store and a secondary mass flow rate (DHW) of 1200 kg/h. The non-standard Type 805 was used which is also used in the template solar system.

Nr.	*Description*	*Value(s)*
1,2	specific heat capacity of primary and secondary side fluid respectively	[a]4.19 kJ/kg-K
3	maximum allowed flow rate on primary (hot) side	[a]1400 kg/h
4	temperature set point for secondary side outlet	[a]45 °C
5	overall heat transfer coefficient UA of heat exchanger	17000 [kJ/hK]

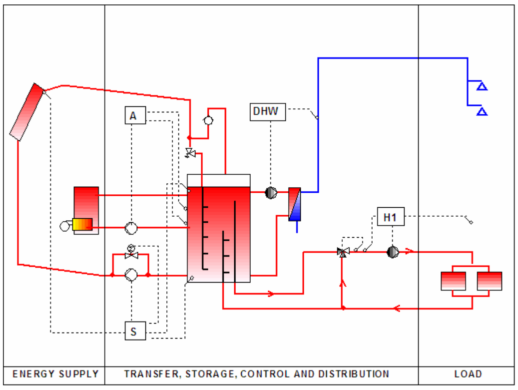
Table 11: Settings of the draw-off heat exchanger

[a] Values according to the template solar system
[b] BC

4 Simulations for testing the library and the accuracy

The used simulation time step is 1/20 (or 1/30) h and the tolerances for convergence and integration are 0.003. No sensitivity analysis has been made for this settings.

5 Sensitivity analysis



MaxLean system

Main parameters (optimised Base Case (BC)):			
building:	*SFH 60*	Storage Volume:	*0.8 m³*
climate:	*Zurich*	Storage height	*1.91 m*
collectors area:	*20 m²*	Position of heat exchangers	-
collector type:	*Standard Flat Plate*	Position of in/outlets	*Typical*
specific flow rate (collector)	*10.2 kg/m²-h*	Thermal insulation	*15 cm*
collector azimuth/tilt angle	*0 / 45 °*	Nominal auxiliary heating rate	*6.1 kW*
collector upper dead band	*7 K*	Heat Exchanger:	*4722 W/K*
simulation parameter:		Storage nodes	*20 l/Node Max. 150*
time step	*1/20 h*	Tolerances Integration Convergence	*0.003 / 0.003*

Table 12: Main parameters of BC

Summary of sensitivity parameters			
Parameter	Variation	[4]Variation in $f_{sav,ext}$	
base Case (BC)	-	35.94 %	
collector size [m^2] (fixed store size (0.8 m^3)	8 – 32	26.34 – 40.58 %	Figure 4
collector size [m^2] (fixed store spec. vol. 0.07 m^3/m^2)	8 – 20	24.87 – 39.58 %	Figure 5
store size [m^3] (fixed collector area of 20 m^2)	0.56 – 1.40	32.59 – 39.63 %	Figure 6
collector azimuth [°] (fixed tilt of 45°)	-90 – 90	27.12 – 36.08 %	Figure 7
collector tilt [°] (fixed azimuth of 0°)	15 – 90	31.77 – 36.36 %	Figure 8
specific collector flow rate [kg/m²-h]	8 - 15	35.96 – 36.09 %	Figure 9
collector upper dead band (K) (with lower dead band = 0.47 * upper dead band)	4 - 12	35.85 – 35.98 %	Figure 10

Table 13: Summary of sensitivity parameters

[4] The variation of fractional savings 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.

Sensitivity parameter:	Collector size [m^2] (fixed store size 0.8 m^3)	8 – 32 m^2

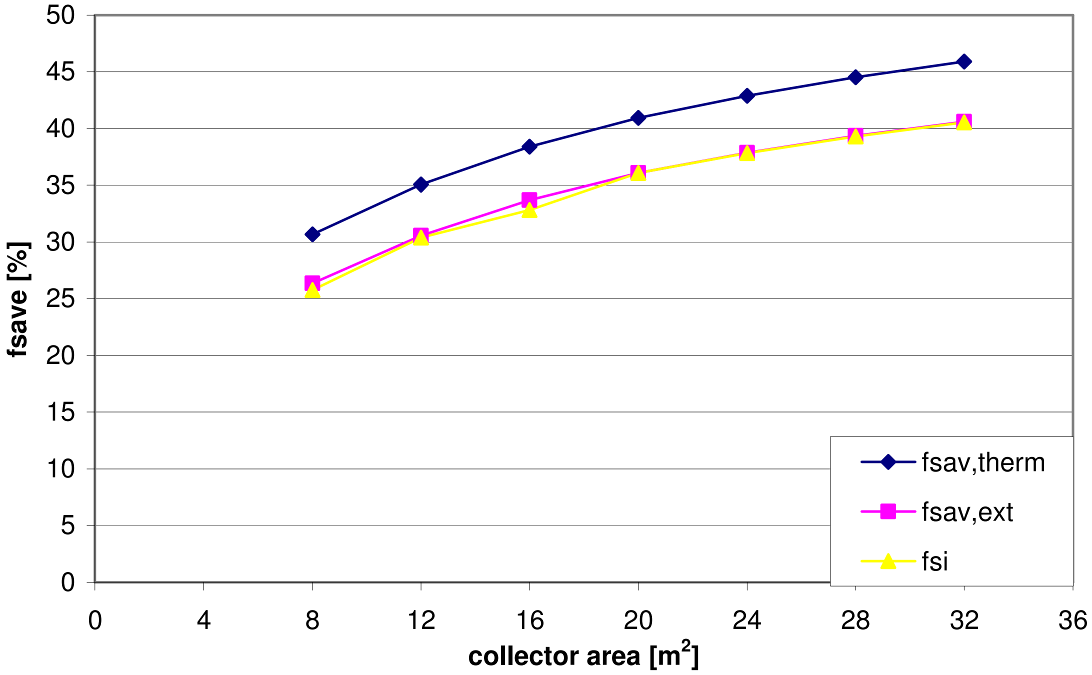


Figure 4: Variation of fractional energy savings with collector size with fixed store volume of 0.8 m^3.

Differences from Base Case (BC)
All settings except the collector area are according to the BC.

Description of results
As expected the increase of savings with increasing collector area decreases the larger the area. By increasing the collector area form 8 m^2 to 12 m^2, $f_{sav,therm}$ rises from 30.67% to 35.05%. By increasing the collector area form 16 m^2 to 20 m^2 $f_{sav,therm}$ rises from 38.89% to 40.94%. From a collector size of 28 m^2 to 32 m^2 the rise is just from 44.53% to 45.89%, but this is still a distinctive rise. There are very few penalties incurred for the settings, so that $f_{si} \approx f_{sav,ext}$.

Comments
None

Sensitivity parameter:	Collector size [m²] (fixed store spec. vol. 0.07 m³/m²)	8 – 20 m²

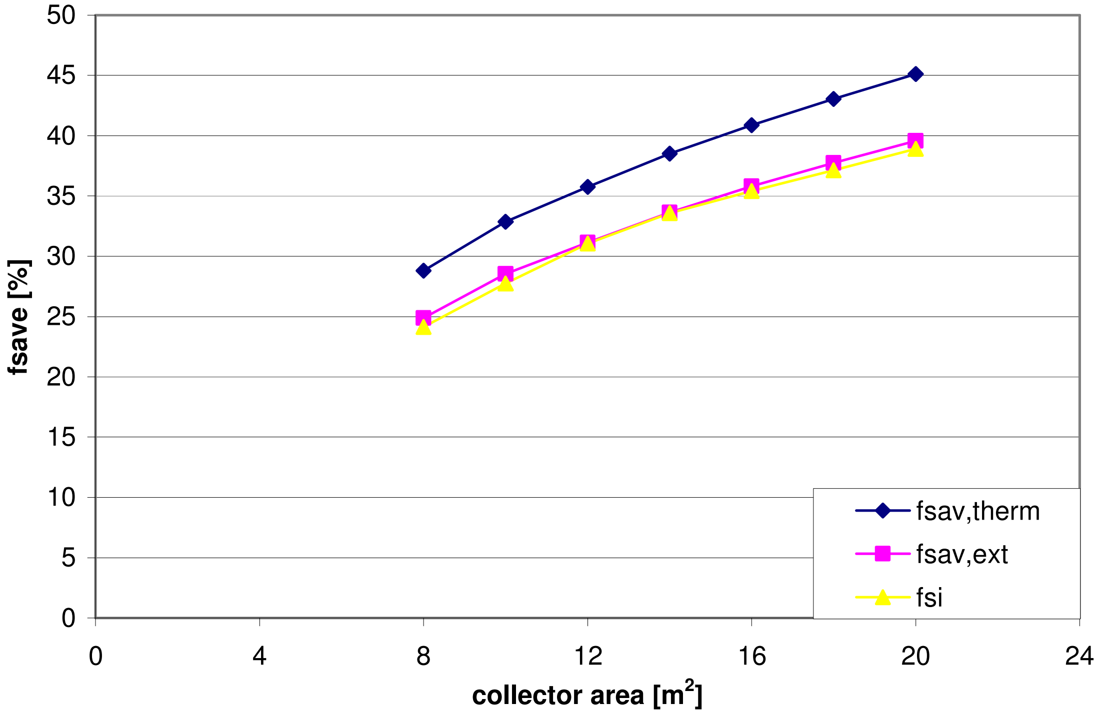


Figure 5: Variation of fractional energy savings with collector size with specific store volume of 0.07 m³/m²

Differences from base case (BC)
The heights of all in- and outlets of the store as well as the positions of the sensors are dependent to the store volume. The store volume is calculated dependent to the collector area with 70 litres per m² of collector area.

Description of results
The savings increases considerably faster with increasing collector area compared to a fixed storage size. With an increasing collector area the increase of savings decreases slightly. By a increase from 8 m² to 10 m², $f_{sav,therm}$ rises from 28.80% to 32.82%. From 12 to 14 m², $f_{sav,therm}$ rises from 35.73% to 38.50% and from 18 to 20 m² $f_{sav,therm}$ still rises from 43.05% to 45.10%.

Comments
Although the building of the BC have a comparatively high energy demand of 60 kWh/m²-a, the system reaches a high $f_{av,therm}$ of nearly 50% with a not too big collector area of 20 m². That means that there is a potential for a further increasing of $f_{sav,therm}$.

Sensitivity parameter:	Store volume [m³] (fixed collector area of 20 m²)	0.56 – 1.4 m³

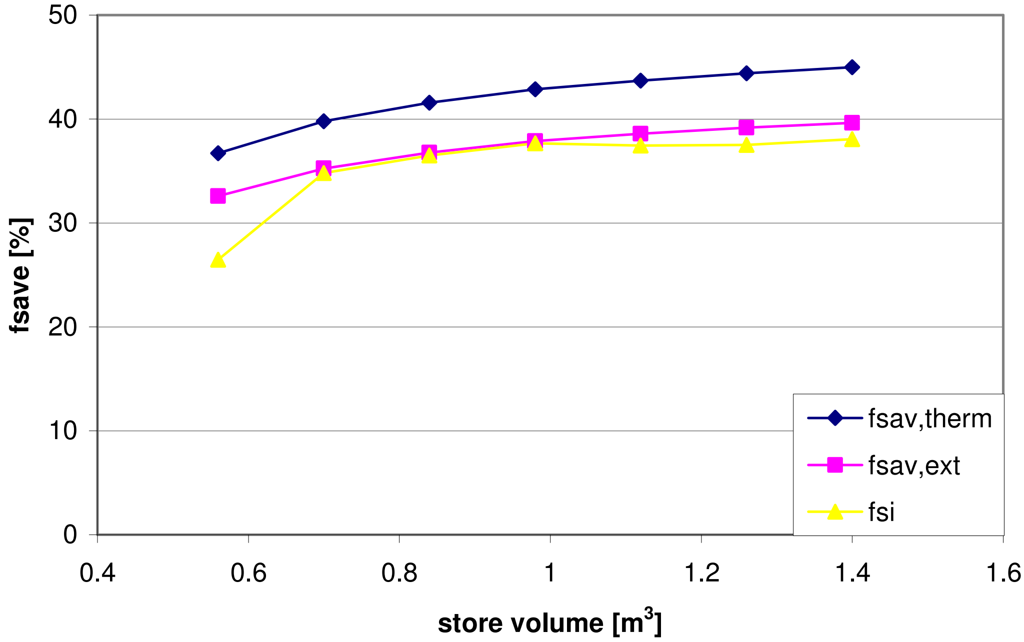


Figure 6: Variation of fractional energy savings with store volume with fixed collector area of 20 m^2

Differences from base case (BC)
The heights of all in- and outlets of the store as well as the positions of the sensors are dependent to the store volume. The heights are optimized for the BC of 800 litres. The collector area is fixed to 20 m^2.

Description of results
The savings increases with an increasing storage volume. The increase of the savings decreases with an increasing storage volume.

Comments
With a storage size around the optimized volume of 800 litres there are very few penalties incurred. With a decreasing storage volume the penalties increases and the f_{si} gets smaller than $f_{sav,ext}$.

Sensitivity parameter:	Collector azimuth [°] (fixed tilt of 45°)	-90 – 90°

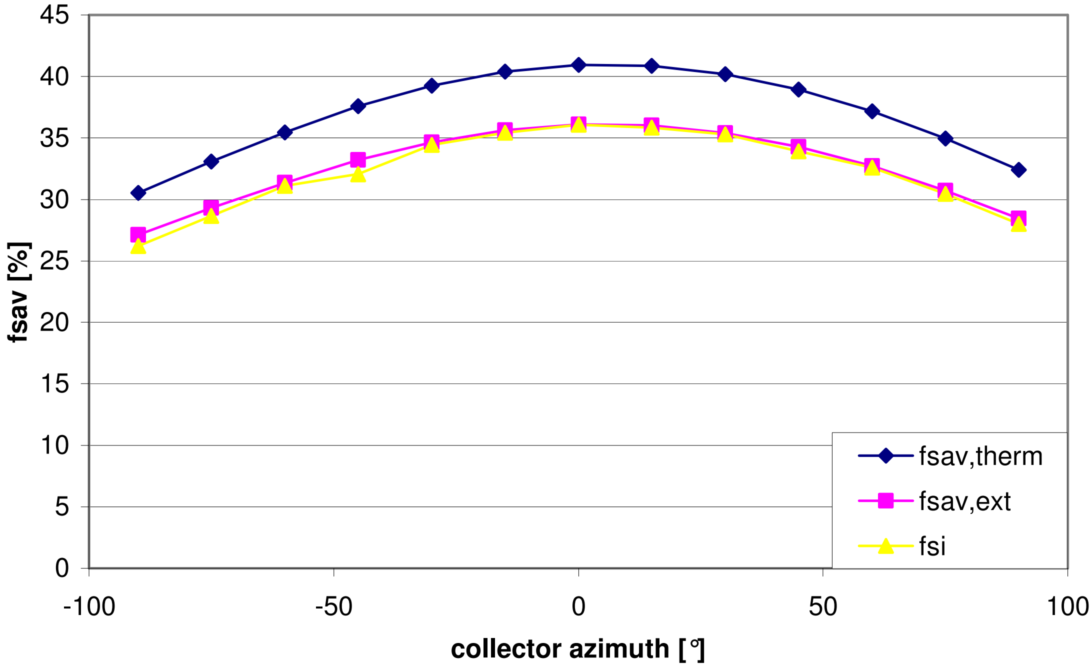


Figure 7: Variation of fractional energy savings with collector azimuth with fixed tilt of 45°

Differences from base case (BC)
The collector azimuth is varied between -90° and 90°. The tilt of the collector is fixed to 45°.

Description of results
The highest fractional savings are achieved with southward orientation that tends slightly towards west. The decrease in fractional savings towards west and east is unincisive between around 20° to east and 35° to west.

Comments
Note that the weather files are synthetic weather files and cloudiness may be dissimilar form one place to another.

Sensitivity parameter:	Collector tilt [°] (fixed azimuth of 0°)	15 – 90°

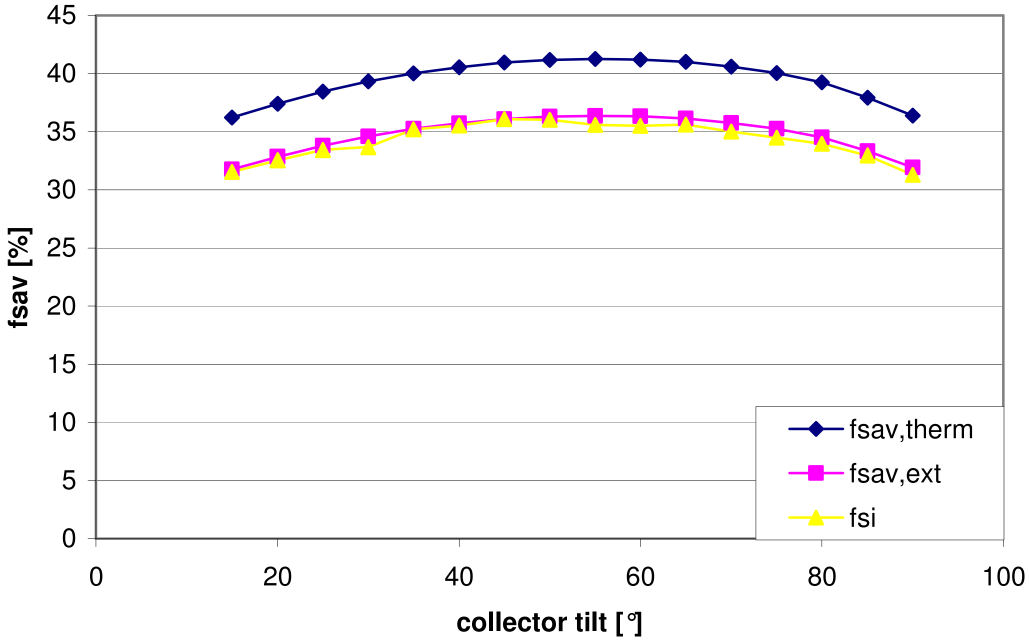


Figure 8: Variation of fractional energy savings with collector tilt with fixed azimuth of 0°

Differences from base case (BC)
The collector tilt is varied between 15° and 90°. All other settings are according to the BC.

Description of results
The highest fractional savings are achieved with a collector tilt of 50°. Between 40 and 70° isn't a remarkable difference in savings.

Comments
Note that the specific collector area of this sensitivity analysis is comparatively big. With another collector area another tilt may be the result.

Sensitivity parameter:	Specific collector flow rate [kg/m²-h]	8 – 15

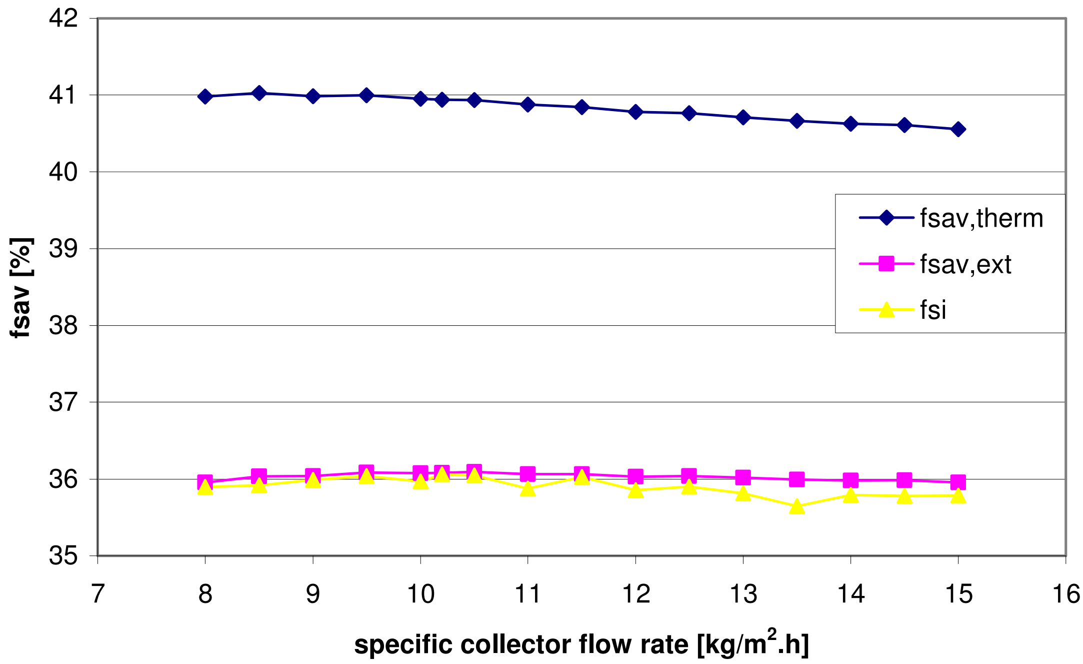


Figure 9: Variation of fractional energy savings with specific collector flow rate

Differences from base case (BC)
The specific flow rate of the collector fluid is varied. All other settings are according to the BC.

Description of results
The specific flow rate of the collector loop isn't a sensitive parameter. The differences of the savings are very small. The best value is around 10 kg/m²-h.

Comments
None

Sensitivity parameter:	Collector upper dead band (°K) (with lower dead band = 0.47 * upper dead band)	4 – 12

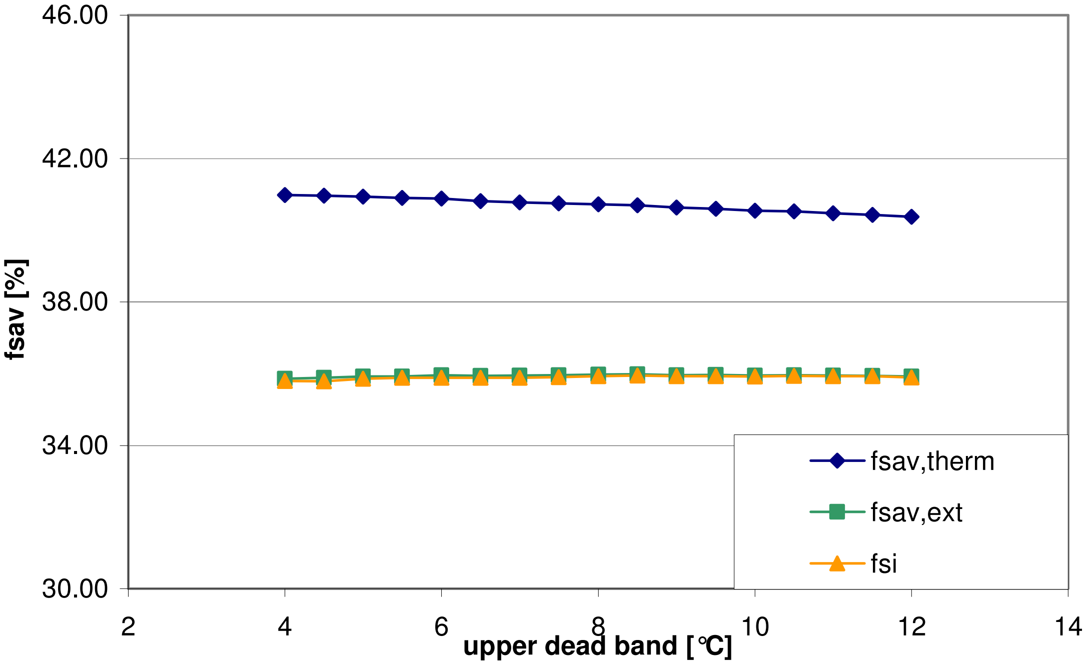


Figure 10: Variation of fractional energy savings with collector upper dead band with lower dead band = 0.47 upper dead band

Differences from base case (BC)
The upper dead band of the collector is varied. The lower dead band is calculated dependent to the upper dead band with 0.47 * upper dead band. All other settings are according to the BC.

Description of results
The dead band for the control of the collector pump isn't a sensitive parameter. A variation between 4 and 12 K leads to a variation in $f_{sav,therm}$ of 0.5 %. The variation in fractional thermal energy savings is bigger than the variation in extended fractional savings because of a longer running time of the collector pump.

Comments
None

6 Results

6.1 Effect of specific features

In the previous chapters of this work two simulation environments were generated: the solar reference system and the MaxLean system. The MaxLean system was generated by successively modifying the solar reference system. By reviewing the results of intermediate steps and comparing both optimized systems the effect of the implemented measures can be quantified.
Table 14 shows an overview of the executed simulations. The alphabetic character in the first column of the table indicates the subsequent change made (with regard to the previous variant, e.g. b is based on a, b is based on c, etc.):

a	Optimized solar reference system.
b	New control (DFFC) implemented to the space heating system.
c	Conversion to a drainback system.
d	Stratifying device for return flow of the space heating implemented.
e	Optimized MaxLean system.

Table 14: Overview of subsequent changes to transform the SRC into the MaxLean system

	$f_{sav,therm}$	$f_{sav,ext}$	f_{si}	$Q_{dp\text{-}sol}$	$Q_{dp\text{-}aux}$	$Q_{dp\text{-}sh}$	$Q_{dp\text{-}dhw}$	$Q_{pen,45}$	Q_{aux}	W_{el}
	[-]	[-]	[-]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]
a	0.403	0.356	0.356	5187	7871	-8490	-3046	43.3	8544	698
b	0.415	0.366	0.332	5297	7736	-8491	-3045	592.0	8375	703
c	0.421	0.373	0.325	5379	7668	-8489	-3045	803.1	8287	693
d	0.428	0.379	0.372	5474	7559	-8488	-3046	168.8	8180	695
e	0.430	0.379	0.382	5477	7545	-8491	-3047	3.0	8162	705

Table 15: Results of both systems with successive modifications. Saving functions: see 4.3; $Q_{dp\text{-}sol}$ = energy transfered through store doubleport used for collector loop; $Q_{dp\text{-}aux}$ = energy transfered through store doubleport used for auxiliary loop; $Q_{dp\text{-}sh}$ = energy transfered through store used for space heating loop; $Q_{dp\text{-}dhw}$ = energy transfered through store doubleport used for draw-off loop

All simulation results are generated with the same system dimensions: 800 litres storage tank and 20 m^2 collector area. The saving functions used to evaluate the energetic behaviour of the systems are the functions described in chapter 4.3. Both systems are compared to a non-solar reference system instead of one another.
The base case of the optimized SRS (a) reaches extended fractional energy savings ($f_{sav,ext}$) of 35.6 %. The fractional savings indicator (f_{si}) is equal to this value because very few penalty functions are included.
The first change made (a → b) is concerning the space heating control. After the system was changed from a supply temperature controlled to a supply flow controlled system the fractional energy savings increased to 36.6 % and the fractional savings indicator declined to 33.2 %. The $f_{sav,ext}$ is 2.8% higher than the starting point (SRS, a) while the f_{si} is 6.7 % lower due to the penalty functions included. The extended energy savings comes from the lower return temperature of the space heating system. This leads to higher effectiveness of the condensing gas boiler and the solar collectors. The height of inlet to the storage from the heating system was not changed from (a) in which it is already optimized to fit the requirements of a supply temperature controlled heating system. There is a further potential of optimization which will be exploit later.
The next point was the conversion to a drainback system (b → c) by removing the heat exchanger and changing the fluid in the collector loop from brine to water. As shown in

table 15 this change reflects an extended fractional energy saving of 1.9 % (compared to the direct feed flow controlled system) and a fractional savings indicator decline of 2.1 %. The natural gas consumption is 88 kWh lower but the added energy due to penalty functions for not meeting the required DHW-temperature amounts to 211 kWh.
The MaxLean system consisted of the implementation of a stratifying device for the return flow of the space heating system (c → d). A fair comparison with the previous system is not possible in this case because the inlet height of the return flow from the space heating was not adjusted to the new control strategy. If an evaluation of the stratifying device should be done the inlet height must be optimized before the results can be compared.
The last line in table 15 shows the results generated with the optimized MaxLean system. These values can be compared to the first line representing the optimized SRS.
The fuel consumption of the MaxLean system (natural gas) is 382 kWh lower then the fuel consumption of the SRS. The difference in the energy balance of the double port 3 - which means the flow rate from and to the auxiliary boiler - is 326 kWh. That implicates that the boiler efficiency of the MaxLean system is slightly better than that of the SRS due to a lower return temperature. This may result from a better stratification of the storage tank. The difference of 290 kWh from doubleport 1 (which is the solar loop doubleport) shows that the fraction of energy delivered by solar with the drainback system is higher than that of the SRS. The difference between the systems in fractional energy savings amounts to 6.5 % and the difference of the fractional savings indicator is 7.3 %.
The comparison of the systems showed that the respective implementations led to a respective improvement in the energetic behaviour while the fractional savings indicator declined. With the final optimization of the MaxLean system the penalty functions could be reduced to a minimum without worsening the energy performance.

6.2 Economic optimization of system dimensions

During the optimization of the system two parameters weren't taken into account:
The storage size and the size of the collector array.
The storage size was fixed to 800 litres and the collector size varied between systems. The focus in this chapter is to find the best values for these parameters in the case of a building with an energy demand of 60 kWh/m^{2}a in Zurich. Naturally the highest energy savings are achieved with a large collector area. However, this is not an economical solution. In extreme cases it is not even an environmentally favourable solution, because a large collector area means much material use with its impairing effects on the environment and resources. Therefore a new criterion over and above the best energetic performance had to be introduced. This criterion is an evaluation of the cost and the benefit of the solar combisystem. The criterion used and the elaboration of it is described in the next section.

6.2.1 Objective function

The mathematical description of an optimisation criterion is called an objective function. In this chapter the objective function used for dimensioning the MaxLean system is described. If an investment is considered to be economically feasible (ie. if it allows the earning or saving of money) this makes for a logical optimisation criterion, however, if an investment is not economically feasible, the objective for making the investment is not as self-evident. Equally, the criterium used to optimize the investment sum are not self-evident. A person who decides to invest in the installation of a solar combisystem does not search to gain or save money, because, if the person did, he or she would not have any solar combisystem installed. Not to install any solar combisystem at all would – from a purely economical point of view – be the best thing to do. Therefore it is assumed that the benefit desired from the investment is different from saving or earning money. It is assumed that the desired benefit is to save energy. This choice is somewhat arbitrary. A presumably better choice than energy savings would be the total effect on the environment. Primary energy savings is chosen to reflect this benefit. This is a practical and transparent choice: Data for the estimation of embodied energy is available and, even though debated, conversion factors to convert from final to primary energy are also available. Because primary energy can be related to CO_2 emissions, results are meaningful with regard to the effect of the combisystem on the environment. However, minimizing primary energy consumption would be to ignore that money is a limited resource and a very large and uneconomic system would result. A compromise between energy savings and financial savings has to be found. If the benefit shall be optimized with respect to the additional cost incurred, the lowest cost per benefit is the objective. According to the above considerations, the cost-benefit ratio to be minimized is the additional annual costs (compared to a non-solar reference system) divided by the primary energy savings resulting from the solar combisystem

$$\text{objective} = \min \frac{\text{additional cost}}{\text{primary energy savings}} \qquad \text{Eq. 1}$$

The following two sections describe how the two components of the objective function - the additional cost and the primary energy savings - are determined.

6.6.1.1 Additional yearly cost

The additional yearly cost of a solar combisystem is the sum of investment costs of the system, evenly spread over the economic life-time of the combisystem, and the running costs in the period under review minus the running costs of a non-solar reference system. That means it is the difference between a system with additional solar part and a non-solar reference system.
The sum of investment costs and running costs in a period under review are the annual costs of solar combisystems. They are calculated with the annuity method. Therefore the investment and the running costs of a solar combisystem are needed.

Investment cost
The investment costs of solar combisystems are dependent to their dimensions which are the sought-after point in this chapter. Therefore a cost function of solar combisystems is needed. The main parts thereby are:

- Solar combistore
- Collector array
- Installation costs
- Maintenance

Solar combistore
To get a volume dependent function of the cost of the storage, data of “Marktübersicht Solarspeicher” [10] were analyzed. This is a database containing around 1000 data sets of solar water stores. The prices are list prices in Germany without VAT. Because non-pressurized storage tanks have not been a common technology until now, there are very few of those tanks contained in this database. That is the reason for analyzing the data irrespective of whether the tanks are pressurized or not. The criteria for taking the tanks into account were as follows:

- combistore
- no tank-in-tank design (no DHW-tank immersed in buffer tank volume)
- included stratifying devices
- without boiler or other heating devices (burner, immersion heater etc.)

Furthermore, the detailed engineering drawings (if available) were appraised whereby tanks with uncommon designs were removed from the list. The remaining data sets were printed into a chart of the specific cost versus the storage size (see figure 11). A trend line of those points leads to the following exponential smoothing function of the specific cost of solar combistores.

$$f(V_{Store}) : c_{store,specific} = 3347.4\ V_{store}^{-0.3464} \qquad \text{Eq. 2}$$

$c_{store,specific}$ [€/m^3] specific cost of combistore
V_{store} [m^3] store volume

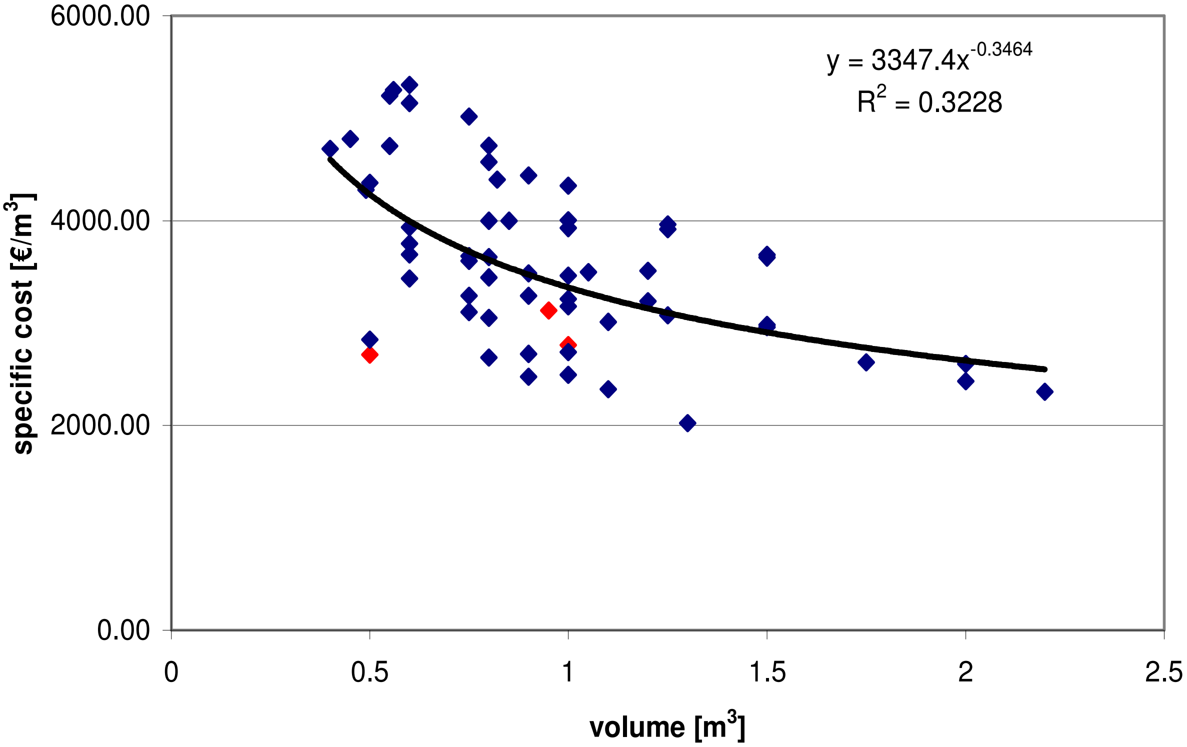


Figure 11: Specific cost of solar combisystems

The red dots in the chart represent non-pressurized tanks. All of them are located below the trend line. With the exception of ROTEX' 500l tank made from polypropylene (leftmost red dot in figure 11) the non-pressurized tanks included in the graph dispose of expensive integrated devices. The position of the red dots below the fitted line justifies the above said statement that non-pressurized tanks tend to be less expensive than pressurized tanks. Nevertheless the shown function was used to take the cost of the store into account. However, it should be kept in mind, that this function does not reflect the potential lower cost of non-pressurized tanks. Also it is important to be aware that the whole cost of the combistore is taken into account. This was done even although it was postulated above that the *additional* cost is considered. This is a worst case assumption. It is justified if the solar store replaces a new existing water heater store. Nevertheless, the combistore may replace an existing water heater store which is partially or fully depreciated. In case of a new installation without solar heating, a new water heater store would have to be purchased. In this case the cost difference between the combistore and a new water heater store would have to be considered instead of the full cost of the combistore.

Solar collectors

The cost of flat plate collectors was taken from SPF InfoCD 2004. This CD contains a database of collectors tested in the institute. The collectors have been sorted for flat plate collectors with a selective coating and the average price of them has been calculated.

$$C_{collector,average} = \sum_{i=1}^{n} C_{collector,i} / i \qquad \text{Eq. 3}$$

The average cost of the 59 listed flat plate collectors with a selective coating is 309 €/m^2.

Installation cost

According to NEGST [3] the installation cost in Germany are 2150 €. These costs are without VAT. By adding the VAT (calculated for Germany with 19 %) the following formula results:

$$I_0 = 2559 + C_{Area} * 368 + 3983.4 * V_{Store}{}^{0.6536} \qquad \text{Eq. 4}$$

I_0 [€]	investment
C_{Area} [m^2]	collector area
V_{Store} [m^3]	storage volume

Running costs

The running costs consist of the fuel costs and the maintenance. The maintenance is usually packaged with the gas boiler and is charged at the flat rate of 30 €/a to account specifically for maintenance of the solar parts. Energy costs are assumed at 5.8 ct/kWh (0.058 €/kWh) for natural gas and 14.5 ct/kWh for electricity. These rates are considered to be representative for Germany in 2007. The service life is assumed to be 20 years. This is a typical assumption for solar heating systems. The rise of energy costs during the service life is considered to be 0.3 %/a for electricity and 1.3 %/a for natural gas for the given period of 2000 – 2030 [13]. Because of the notoriously high incertitude of energy price prognosis a sensitivity analysis was carried out.

The running costs are dependent on the energy costs. A constant rise in energy prices during the period under observation is assumed. Therefore the energy costs can be calculated as average annual energy costs with the coefficient for levelised cost calculation [14]. With this information the annuity can be calculated:

$$AN = -a\ I_0 + B \qquad \text{Eq. 5}$$

$$a = \frac{i\,(1+i)^{\,n}}{(1+i)^n - 1} \qquad \text{Eq. 6}$$

$$B = Q_{gas} * 0.058 * m_{gas} + W_{el} * 0.145 * m_{el} + 30 \qquad \text{Eq. 7}$$

$$m = \frac{\left(1+\frac{i-e}{1+e}\right)^n - 1}{\left(\frac{i-e}{1+e}\right) * \left(1+\frac{i-e}{1+e}\right)^n} * a \qquad \text{Eq. 8}$$

AN [€]	annual average expenditure
a [-]	annuity factor
i [-]	calculatory interest rate
n [years]	service life
e [-]	rise in energy prices (inflation-adjusted)
I_0 [€]	investment
B [€]	annual cost of operation
m_{el} [-]	coefficient for levelised electricity cost calculation
m_{gas} [-]	coefficient for levelised natural gas cost calculation

The additional yearly costs are:

$$\text{additional yearly cost} = AN - B_{ref}$$

6.6.1.2 Primary energy savings

The annual **primary energy savings** are calculated from the difference from the energy consumption in the solar and the non-solar system to the embodied energy of the solar system.

$$E_{prim,sav} = E_{prim,ref} - E_{prim,MaxLean} \qquad \text{Eq. 9}$$

The fuel consumption needs to be converted to primary energy consumption with the factors $f_{P,gas}$ and $f_{P,el}$, each adopted from DIN 4701-10: Energetische Bewertung heiz- und raumluft-technischer Anlagen ($f_{P,gas}$ = 1.1; $f_{P,el}$ = 3). To get annual values of the embodied energy, the total amount is divided by the service life, which is also the period under observation (in this case 20 years).

$$E_{prim,ref} = W_{el,ref} * f_{P,el} + Q_{gas,ref} * f_{P,gas} \qquad \text{Eq. 10}$$

$$E_{prim,MaxLean} = W_{el,MaxLean} * f_{P,el} + Q_{gas,MaxLean} * f_{P,gas} - E_{emb} / 20 \qquad \text{Eq. 11}$$

$W_{el,ref}$ [kWh] auxiliary energy (electricity) consumption of the reference system = 661.2 kWh

$Q_{gas,ref}$ [kWh] fuel consumption of reference system = 14312 kWh

The embodied energy can be divided into the parts consisting of the store and the solar collectors (where the piping is included in the collector term).

$$E_{emb} = E_{emb,store} + E_{emb,coll} \qquad \text{Eq. 12}$$

$$E_{emb,store} = V_{steel} * \rho_{steel} * E_{spec,steel} + V_{insulation} * \rho_{insulaton} * E_{spec,insulation} \qquad \text{Eq. 13}$$

$$E_{emb,coll} = E_{emb,coll,spec} * C_{Area} \qquad \text{Eq. 14}$$

$$V_{steel} = 0.01\left(d_S{}^2 \frac{\pi}{2} + d_S\, h_S\, \pi \right) \qquad \text{Eq. 15}$$

$$V_{insulation} = 0.15\left((d_S + 0.3)^2 \frac{\pi}{2} + d_S\, h_S\, \pi \right) \qquad \text{Eq. 16}$$

$E_{emb,coll,spec}$ [kWh/m²] specific embodied energy of the collector = 250

d_S [m] diameter of store

h_S [m] height of storage

material	density [kg/m³]	specific embodied energy [MJ/kg]
steel plate	**7850**	**27.10**
PUR heat insulation	**30**	**97.70**

Table 16: Material properties used for the calculation of the embodied energy [15]

The following objective function results from the formulae for calculating the additional yearly cost and the primary energy savings:

$$\text{objective function} = \min \frac{a * I_0 + B_{MaxLean} - B_{ref}}{E_{prim,sav}} \qquad \text{Eq. 17}$$

6.2.2 Resulting dimension

The dimensioning of the MaxLean system was calculated with GenOpt. The initial point for the dimensioning was a storage volume of 800 litres and a collector size of 12 m². The rise of energy prices was defined as 1.3 %/a for natural gas and 0.3 %/a for electricity. Figure 12 shows the result of the first dimensioning with the above declared objective function. The resulting optimised system has a storage volume of 700 litres and a collector area of 10 m². It saves 4712.25 kWh of primary energy a year. The additional cost amounts to 365.51 €/a. For completeness by comparison, a second optimization was performed using a different objective function: the minimum additional cost without respect to energy savings. That means the objective was just to minimize the annuity, AN (optimization of annuity in Figure 12). This leads to a considerably smaller system that causes 277.25 €/a additional costs and saves 2676.34 kWh/a primary energy. The dimensions of this system are: 425 litres storage volume and 3.7 m^2 collector area.

Each dot in the chart represents a simulation result using different values of the two parameters: collector area and storage volume. A polynomial interpolation can be added indicating the lowest ratio of additional cost to primary energy saving for the given set of varyingly dimensioned systems. The closer the dots are to this line the better the symbiosis between storage volume and collector area is.

Drawing a line form the origin tangentially meeting this polynomial leads to the point with the lowest cost per benefit.

This optimization was calculated with different rates of increases in energy costs. The result is shown in Figure 13.

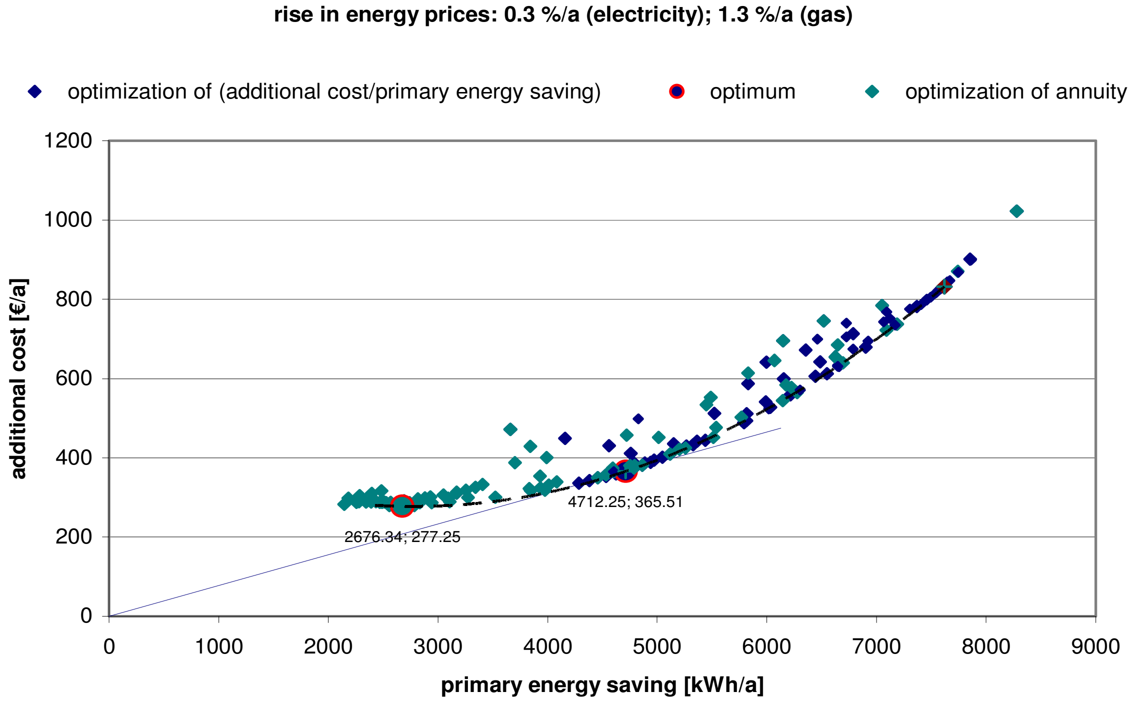


Figure 12: Dimensioning of the MaxLean system with different objective functions. (a_{el} = 0.3 %/a; a_{gas} = 1.3 %/a)

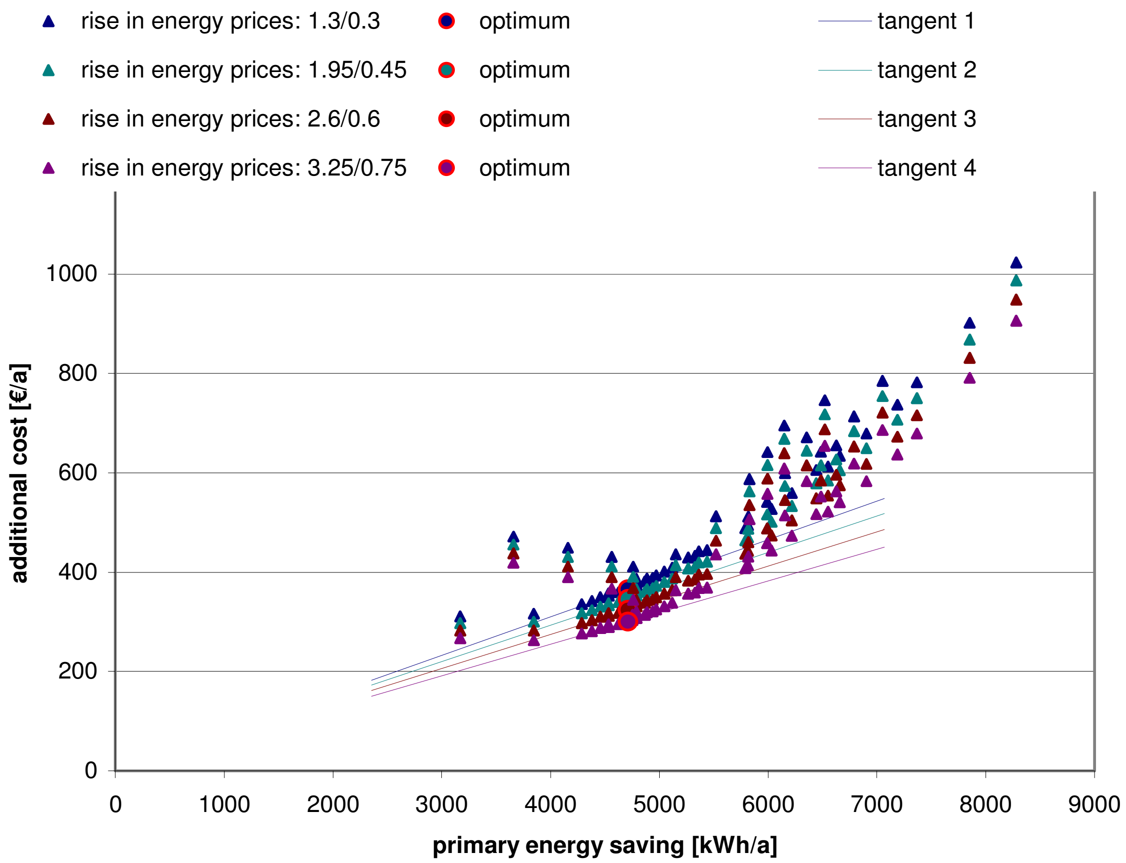


Figure 13: Dimensioning of the MaxLean system with different rises in energy prices

In figure 13 the result of the sensitivity analysis is shown. The rise in energy prices for natural gas was varied from 1.3 %/a to 3.25 %/a, the rise in prices for electricity was varied from 0.3 %/a to 0.75 %/a, which is quite a conservative choice. In table 17 the results of the system dimensions with the best cost-benefit ratio to the respective rises in energy prices are shown.

$e_{el/gas}$	I_0	B_{sol}	B_{ref}	AN	$E_{prim,sav}$	$\frac{AN-B_{ref}}{E_{prim,sav}}$	V_{Store}	C_{Area}
[%]	[€]	[€/a]	[€/a]	[€/a]	[kWh/a]	[-]	[m^3]	[m^2]
0.3/1.3	9382.58	774.99	1039.98	1405.51	4712.25	0.0776	0.700	9.97
0.45/1.95	9382.58	818.87	1103.93	1449.38	4712.25	0.0733	0.700	9.97
0.6/2.6	9382.58	866.27	1173.06	1496.77	4712.25	0.0687	0.700	9.97
0.75/3.25	9382.58	917.51	1247.83	1548.01	4712.25	0.0637	0.700	9.97

Table 17: Results of system dimensioning

Within the examined range of energy price increases the resulting dimensioning for all systems is the same: 700 litres tank and 10 m^2 collector area.

That means that within the examined range the dimensioning of the collector area and the storage volume is independent from the rises in energy prices - which is a surprising result. Note that the step size of GenOpt is limited. For all the different energy price rises this is the reason why *exactly* the same system was found to have the best cost-benefit ratio. However surprising this result may be, the situation is illustrated by figure 13: The different curves are situated at different levels (of additional cost), but the higher the level, the higher the inclination of the curve. As a consequence, the points which represent the best cost-benefit ratio are above one another. They represent systems which save the same amount of energy and are of equal size.

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8 Appendix 1: Analysis using FSC

Building Climate		SFH100 Barcelona						
A_{col}	[m²]	8	12	16	20	24	28	32
V_{Store}	[m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$	[kWh/a]	5887	6941	7659	7790	7790	7790	7790
E_{aux}	[kWh/a]	3481	2875	2505	2220	2065	1955	1846
E_{ref}	[kWh/a]	7790	7790	7790	7790	7790	7790	7790
E_{total}	[kWh/a]	4898	4231	3825	3519	3348	3229	3114
$E_{total,ref}$	[kWh/a]	10008	10008	10008	10008	10008	10008	10008
$Q_{in,store}$	[kWh/a]	7598	7778	7900	7982	8030	8064	8085
$Q_{out,store}$	[kWh/a]	5989	5990	5990	5989	5989	5990	5989
$Q_{st,aux}$	[kWh/a]	2908	2359	2015	1758	1618	1515	1423
$Q_{st,coll}$	[kWh/a]	4689	5419	5885	6223	6413	6549	6663
$Q_{st,dhw}$	[kWh/a]	2827	2827	2827	2827	2827	2827	2827
$Q_{st,sh}$	[kWh/a]	3162	3162	3162	3163	3163	3163	3162
$W_{pump,sol}$	[kWh/a]	212.61	189.67	176.38	168.37	162.45	158.90	156.78
W_{burn}	[kWh/a]	89.21	87.85	87.01	86.37	86.02	85.78	85.55
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	247.96	248.00	248.05	248.00	248.03	248.00	248.06
$W_{pump,DHW}$	[kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total}	[kWh/a]	566.58	542.33	528.25	519.54	513.30	509.48	507.20
$Q_{pen,45}$	[kWh/a]	0.03	0.00	0.00	3.28	0.56	0.00	0.00
$Q_{pen,25}$	[kWh/a]	9124.84	9124.84	9124.84	9124.84	9124.84	9124.84	9124.84
$Q_{pen,20}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$	[kWh/a]	0.03	0.00	0.00	3.28	0.56	0.00	0.00
FSC		0.756	0.891	0.983	1.000	1.000	1.000	1.000
$f_{sav,therm}$		0.553	0.631	0.678	0.715	0.735	0.749	0.763
$f_{sav,ext}$		0.511	0.577	0.618	0.648	0.665	0.677	0.689
f_{si}		0.511	0.577	0.618	0.648	0.665	0.677	0.689

Table 18: Results of MaxLean system simulations for the Climate Barcelona with SFH100 with 800 litres storage tank

Building Climate	SFH100 Barcelona						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	5887	6453	6941	7300	7659	7790	7790
E_{aux} [kWh/a]	3758	3233	2834	2517	2246	2028	1834
E_{ref} [kWh/a]	7790	7790	7790	7790	7790	7790	7790
E_{total} [kWh/a]	5140	4604	4194	3868	3592	3367	3171
$E_{total,ref}$ [kWh/a]	10008	10008	10008	10008	10008	10008	10008
$Q_{in,store}$ [kWh/a]	7423	7612	7811	8005	8188	8356	8524
$Q_{out,store}$ [kWh/a]	5987	5988	5989	5990	5990	5990	5990
$Q_{st,aux}$ [kWh/a]	3169	2682	2321	2025	1779	1579	1402
$Q_{st,coll}$ [kWh/a]	4254	4930	5490	5980	6409	6778	7122
$Q_{st,dhw}$ [kWh/a]	2827	2827	2827	2827	2827	2827	2827
$Q_{st,sh}$ [kWh/a]	3161	3161	3163	3162	3163	3163	3163
$W_{pump,sol}$ [kWh/a]	198.23	194.94	191.42	188.67	186.95	185.12	184.54
W_{burn} [kWh/a]	89.92	88.67	87.78	87.00	86.42	85.90	85.45
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	248.09	248.05	248.10	247.93	248.05	248.00	248.06
$W_{pump,DHW}$ [kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total} [kWh/a]	553.05	548.46	544.10	540.40	538.22	535.82	534.85
$Q_{pen,45}$ [kWh/a]	1.03	0.00	0.00	4.03	0.00	0.57	1.27
$Q_{pen,25}$ [kWh/a]	9124.84	9124.84	9124.84	9124.84	9124.84	9124.84	9124.84
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	1.03	0.00	0.00	4.03	0.00	0.57	1.27
FSC	0.756	0.828	0.891	0.937	0.983	1.000	1.000
$f_{sav,therm}$	0.518	0.585	0.636	0.677	0.712	0.740	0.765
$f_{sav,ext}$	0.486	0.540	0.581	0.613	0.641	0.664	0.683
f_{si}	0.486	0.540	0.581	0.613	0.641	0.663	0.683

Table 19: Results of MaxLean system simulations for the Climate Barcelona with SFH100 with specific storage volume of 0.07 m^3/m^2

Building Climate	SFH60 Barcelona						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	5092	5574	5574	5574	5574	5574	5574
E_{aux} [kWh/a]	1654	1259	1034	904	808	757	715
E_{ref} [kWh/a]	5574	5574	5574	5574	5574	5574	5574
E_{total} [kWh/a]	2755	2292	2029	1875	1763	1701	1653
$E_{total,ref}$ [kWh/a]	7525	7525	7525	7525	7525	7525	7525
$Q_{in,store}$ [kWh/a]	5774	5964	6099	6178	6226	6253	6273
$Q_{out,store}$ [kWh/a]	4102	4103	4103	4102	4102	4102	4102
$Q_{st,aux}$ [kWh/a]	1315	961	757	639	553	508	469
$Q_{st,coll}$ [kWh/a]	4459	5004	5342	5538	5673	5746	5804
$Q_{st,dhw}$ [kWh/a]	2827	2827	2827	2827	2827	2827	2827
$Q_{st,sh}$ [kWh/a]	1275	1275	1275	1275	1275	1275	1275
$W_{pump,sol}$ [kWh/a]	205.35	179.34	164.97	155.75	149.50	145.30	142.80
W_{burn} [kWh/a]	85.49	84.24	83.51	83.10	82.79	82.64	82.50
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	133.04	133.05	133.08	133.03	133.13	133.06	133.14
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	440.43	413.17	398.11	388.41	381.96	377.54	374.99
$Q_{pen,45}$ [kWh/a]	2.76	2.39	0.00	0.00	0.00	0.00	0.00
$Q_{pen,25}$ [kWh/a]	9967.05	9967.05	9967.05	9967.05	9967.05	9967.05	9967.05
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	2.76	2.39	0.00	0.00	0.00	0.00	0.00
FSC	0.914	1.000	1.000	1.000	1.000	1.000	1.000
$f_{sav,therm}$	0.703	0.774	0.814	0.838	0.855	0.864	0.872
$f_{sav,ext}$	0.634	0.695	0.730	0.751	0.766	0.774	0.780
f_{si}	0.633	0.695	0.730	0.751	0.766	0.774	0.780

Table 20: Results of MaxLean system simulations for the Climate Barcelona with SFH60 with 800 litres storage tank

Building Climate		SFH60 Barcelona						
A_{col}	[m²]	8	10	12	14	16	18	20
V_{Store}	[m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$	[kWh/a]	5092	5451	5574	5574	5574	5574	5574
E_{aux}	[kWh/a]	1858	1483	1233	1040	882	735	630
E_{ref}	[kWh/a]	5574	5574	5574	5574	5574	5574	5574
E_{total}	[kWh/a]	2928	2535	2270	2066	1901	1748	1639
$E_{total,ref}$	[kWh/a]	7525	7525	7525	7525	7525	7525	7525
$Q_{in,store}$	[kWh/a]	5570	5788	6006	6212	6412	6593	6767
$Q_{out,store}$	[kWh/a]	4102	4102	4102	4102	4103	4102	4102
$Q_{st,aux}$	[kWh/a]	1508	1164	937	759	615	483	388
$Q_{st,coll}$	[kWh/a]	4061	4624	5069	5454	5797	6110	6379
$Q_{st,dhw}$	[kWh/a]	2827	2827	2827	2827	2827	2827	2827
$Q_{st,sh}$	[kWh/a]	1275	1275	1275	1275	1275	1275	1275
$W_{pump,sol}$	[kWh/a]	191.96	186.19	181.02	177.26	174.96	173.08	171.56
W_{burn}	[kWh/a]	86.08	84.92	84.17	83.55	83.06	82.60	82.29
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	133.12	133.09	133.03	133.03	133.04	133.08	133.01
$W_{pump,DHW}$	[kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total}	[kWh/a]	427.70	420.74	414.76	410.38	407.62	405.30	403.41
$Q_{pen,45}$	[kWh/a]	13.54	0.08	3.09	0.00	0.00	0.00	0.00
$Q_{pen,25}$	[kWh/a]	9967.05	9967.05	9967.05	9967.05	9967.05	9967.05	9967.05
$Q_{pen,20}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$	[kWh/a]	13.54	0.08	3.09	0.00	0.00	0.00	0.00
FSC		0.914	0.978	1.000	1.000	1.000	1.000	1.000
$f_{sav,therm}$		0.667	0.734	0.779	0.813	0.842	0.868	0.887
$f_{sav,ext}$		0.611	0.663	0.698	0.725	0.747	0.768	0.782
f_{si}		0.609	0.663	0.698	0.725	0.747	0.768	0.782

Table 21: Results of MaxLean system simulations for the Climate Barcelona with SFH60 with specific storage volume of 0.07 m^3/m^2

Building Climate	SFH30 Barcelona						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	4353	4353	4353	4353	4353	4353	4353
E_{aux} [kWh/a]	736	472	383	350	329	317	308
E_{ref} [kWh/a]	4353	4353	4353	4353	4353	4353	4353
E_{total} [kWh/a]	1586	1250	1120	1061	1022	999	984
$E_{total,ref}$ [kWh/a]	6054	6054	6054	6054	6054	6054	6054
$Q_{in,store}$ [kWh/a]	4784	4991	5125	5204	5246	5264	5288
$Q_{out,store}$ [kWh/a]	3063	3064	3064	3063	3063	3064	3064
$Q_{st,aux}$ [kWh/a]	456	234	161	132	114	104	96
$Q_{st,coll}$ [kWh/a]	4328	4757	4964	5072	5133	5160	5192
$Q_{st,dhw}$ [kWh/a]	2827	2827	2827	2827	2827	2827	2827
$Q_{st,sh}$ [kWh/a]	236	236	236	236	236	236	236
$W_{pump,sol}$ [kWh/a]	201.64	173.73	157.37	146.84	139.92	135.44	133.07
W_{burn} [kWh/a]	82.59	81.76	81.49	81.39	81.32	81.28	81.25
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	39.49	39.48	39.46	39.48	39.48	39.49	39.48
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	340.26	311.52	294.86	284.25	277.26	272.76	270.35
$Q_{pen,45}$ [kWh/a]	10.26	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,25}$ [kWh/a]	9565.39	9565.39	9565.39	9565.39	9565.39	9565.39	9565.39
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	10.26	0.00	0.00	0.00	0.00	0.00	0.00
FSC	1	1	1	1	1	1	1
$f_{sav,therm}$	0.831	0.892	0.912	0.920	0.924	0.927	0.929
$f_{sav,ext}$	0.738	0.793	0.815	0.825	0.831	0.835	0.838
f_{si}	0.736	0.793	0.815	0.825	0.831	0.835	0.838

Table 22: Results of MaxLean system simulations for the Climate Barcelona with SFH30 with 800 litres storage tank

Building Climate	SFH30 Barcelona						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$[kWh/a]	4353	4353	4353	4353	4353	4353	4353
E_{aux} [kWh/a]	869	605	464	370	315	282	254
E_{ref} [kWh/a]	4353	4353	4353	4353	4353	4353	4353
E_{total} [kWh/a]	1689	1404	1246	1140	1076	1034	1001
$E_{total,ref}$ [kWh/a]	6054	6054	6054	6054	6054	6054	6054
$Q_{in,store}$ [kWh/a]	4556	4800	5034	5261	5476	5662	5846
$Q_{out,store}$ [kWh/a]	3063	3063	3064	3064	3064	3064	3064
$Q_{st,aux}$ [kWh/a]	578	347	227	148	99	71	47
$Q_{st,coll}$ [kWh/a]	3978	4453	4808	5114	5376	5591	5799
$Q_{st,dhw}$ [kWh/a]	2827	2827	2827	2827	2827	2828	2828
$Q_{st,sh}$ [kWh/a]	236	236	236	236	236	236	236
$W_{pump,sol}$ [kWh/a]	189.08	181.75	175.23	170.33	167.25	163.77	161.83
W_{burn} [kWh/a]	82.99	82.18	81.74	81.45	81.27	81.17	81.09
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	39.45	39.48	39.49	39.48	39.48	39.48	39.49
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	328.06	319.95	313.00	307.80	304.54	300.97	298.96
$Q_{pen,45}$ [kWh/a]	9.56	8.10	0.00	0.00	0.00	0.00	0.45
$Q_{pen,25}$ [kWh/a]	9565.39	9565.39	9565.39	9565.39	9565.39	9565.39	9565.39
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	9.56	8.10	0.00	0.00	0.00	0.00	0.45
FSC	1	1	1	1	1	1	1
$f_{sav,therm}$	0.800	0.861	0.893	0.915	0.928	0.935	0.942
$f_{sav,ext}$	0.721	0.768	0.794	0.812	0.822	0.829	0.835
f_{si}	0.719	0.767	0.794	0.812	0.822	0.829	0.835

Table 23: Results of MaxLean system simulations for the Climate Barcelona with SFH30 with specific storage volume of 0.07 m^3/m^2

Building Climate	SFH15 Barcelona						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	4079	4079	4079	4079	4079	4079	4079
E_{aux} [kWh/a]	530	317	262	241	232	225	223
E_{ref} [kWh/a]	4079	4079	4079	4079	4079	4079	4079
E_{total} [kWh/a]	1283	997	898	850	823	806	797
$E_{total,ref}$ [kWh/a]	5531	5531	5531	5531	5531	5531	5531
$Q_{in,store}$ [kWh/a]	4561	4779	4911	4988	5024	5045	5067
$Q_{out,store}$ [kWh/a]	2831	2832	2832	2831	2831	2832	2831
$Q_{st,aux}$ [kWh/a]	268	95	52	35	28	22	21
$Q_{st,coll}$ [kWh/a]	4293	4684	4860	4953	4996	5022	5047
$Q_{st,dhw}$ [kWh/a]	2827	2827	2827	2827	2827	2827	2827
$Q_{st,sh}$ [kWh/a]	4	4	4	4	4	4	4
$W_{pump,sol}$ [kWh/a]	200.80	172.33	155.19	144.49	137.27	132.94	130.37
W_{burn} [kWh/a]	81.95	81.28	81.11	81.04	81.01	80.99	80.99
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	1.63	1.63	1.64	1.64	1.64	1.64	1.64
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	300.92	271.79	254.48	243.71	236.46	232.11	229.54
$Q_{pen,45}$ [kWh/a]	10.05	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,25}$ [kWh/a]	9570.50	9570.50	9570.50	9570.50	9570.50	9570.50	9570.50
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	10.02	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
FSC	1	1	1	1	1	1	1
$f_{sav,therm}$	0.870	0.922	0.936	0.941	0.943	0.945	0.945
$f_{sav,ext}$	0.768	0.820	0.838	0.846	0.851	0.854	0.856
f_{si}	0.766	0.820	0.838	0.846	0.851	0.854	0.856

Table 24: Results of MaxLean system simulations for the Climate Barcelona with SFH15 with 800 litres storage tank

Building Climate		SFH15 Barcelona						
A_{col}	[m²]	8	10	12	14	16	18	20
V_{Store}	[m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$	[kWh/a]	4079	4079	4079	4079	4079	4079	4079
E_{aux}	[kWh/a]	656	423	308	247	230	215	208
E_{ref}	[kWh/a]	4079	4079	4079	4079	4079	4079	4079
E_{total}	[kWh/a]	1379	1124	991	916	890	867	854
$E_{total,ref}$	[kWh/a]	5531	5531	5531	5531	5531	5531	5531
$Q_{in,store}$	[kWh/a]	4331	4581	4822	5055	5272	5460	5647
$Q_{out,store}$	[kWh/a]	2831	2831	2831	2832	2832	2832	2832
$Q_{st,aux}$	[kWh/a]	381	182	87	39	26	14	8
$Q_{st,coll}$	[kWh/a]	3950	4399	4735	5015	5246	5446	5639
$Q_{st,dhw}$	[kWh/a]	2827	2827	2827	2827	2828	2828	2828
$Q_{st,sh}$	[kWh/a]	4	4	4	4	4	4	4
$W_{pump,sol}$	[kWh/a]	188.46	180.58	173.88	168.46	164.82	161.38	159.32
W_{burn}	[kWh/a]	82.31	81.61	81.25	81.06	81.01	80.96	80.94
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	1.64	1.63	1.64	1.63	1.63	1.63	1.63
$W_{pump,DHW}$	[kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total}	[kWh/a]	288.95	280.36	273.31	267.70	264.00	260.52	258.43
$Q_{pen,45}$	[kWh/a]	10.70	0.85	0.10	0.04	0.00	0.64	0.00
$Q_{pen,25}$	[kWh/a]	9570.50	9570.50	9570.50	9570.50	9570.50	9570.50	9570.50
$Q_{pen,20}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$	[kWh/a]	10.67	0.82	0.07	0.00	-0.03	0.61	-0.03
FSC		1	1	1	1	1	1	1
$f_{sav,therm}$		0.839	0.896	0.924	0.939	0.944	0.947	0.949
$f_{sav,ext}$		0.751	0.797	0.821	0.834	0.839	0.843	0.846
f_{si}		0.749	0.797	0.821	0.834	0.839	0.843	0.846

Table 25: Results of MaxLean system simulations for the Climate Barcelona with SFH15 with specific storage volume of 0.07 m^3/m^2

Building Climate		SFH100 Madrid						
A_{col}	[m²]	8	12	16	20	24	28	32
V_{Store}	[m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$	[kWh/a]	7201	8878	10139	10633	10962	11292	11365
E_{aux}	[kWh/a]	6030	5240	4679	4271	3956	3779	3636
E_{ref}	[kWh/a]	11365	11365	11365	11365	11365	11365	11365
E_{total}	[kWh/a]	7624	6778	6188	5764	5438	5253	5108
$E_{total,ref}$	[kWh/a]	13714	13714	13714	13714	13714	13714	13714
$Q_{in,store}$	[kWh/a]	10615	10760	10857	10931	10984	11011	11032
$Q_{out,store}$	[kWh/a]	9027	9027	9027	9028	9028	9028	9028
$Q_{st,aux}$	[kWh/a]	5344	4604	4077	3689	3396	3228	3094
$Q_{st,coll}$	[kWh/a]	5270	6157	6780	7241	7588	7783	7939
$Q_{st,dhw}$	[kWh/a]	2978	2977	2977	2977	2978	2977	2977
$Q_{st,sh}$	[kWh/a]	6049	6050	6050	6050	6050	6050	6050
$W_{pump,sol}$	[kWh/a]	214.96	194.65	183.77	178.30	174.89	172.06	171.34
W_{burn}	[kWh/a]	94.95	93.15	91.88	90.94	90.22	89.84	89.50
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	310.91	310.99	311.01	310.86	310.97	311.00	311.01
$W_{pump,DHW}$	[kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total}	[kWh/a]	637.62	615.58	603.45	596.90	592.88	589.70	588.65
$Q_{pen,45}$	[kWh/a]	0.87	10.08	3.50	0.70	0.25	17.31	5.58
$Q_{pen,25}$	[kWh/a]	7902.42	7902.42	7902.42	7902.42	7902.42	7902.42	7902.42
$Q_{pen,20}$	[kWh/a]	0	0	0	0	0	0	0
$Q_{pen,red}$	[kWh/a]	0.87	10.08	3.50	0.70	0.25	17.31	5.58
FSC		0.634	0.781	0.892	0.936	0.965	0.994	1.000
$f_{sav,therm}$		0.469	0.539	0.588	0.624	0.652	0.668	0.680
$f_{sav,ext}$		0.444	0.506	0.549	0.580	0.603	0.617	0.628
f_{si}		0.444	0.505	0.549	0.580	0.603	0.616	0.627

Table 26: Results of MaxLean system simulations for the Climate Madrid with SFH100 with 800 litres storage tank

Building Climate	SFH100 Madrid						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	7201	8040	8878	9668	10139	10468	10633
E_{aux} [kWh/a]	6388	5693	5186	4725	4311	3931	3590
E_{ref} [kWh/a]	11365	11365	11365	11365	11365	11365	11365
E_{total} [kWh/a]	7950	7246	6730	6261	5841	5461	5119
$E_{total,ref}$ [kWh/a]	13714	13714	13714	13714	13714	13714	13714
$Q_{in,store}$ [kWh/a]	10446	10613	10794	10955	11111	11270	11422
$Q_{out,store}$ [kWh/a]	9024	9025	9027	9027	9028	9029	9028
$Q_{st,aux}$ [kWh/a]	5685	5032	4552	4115	3727	3371	3052
$Q_{st,coll}$ [kWh/a]	4761	5581	6242	6840	7384	7899	8371
$Q_{st,dhw}$ [kWh/a]	2977	2977	2978	2977	2977	2977	2978
$Q_{st,sh}$ [kWh/a]	6047	6047	6050	6050	6051	6051	6050
$W_{pump,sol}$ [kWh/a]	201.14	199.06	196.55	194.62	193.33	193.77	194.65
W_{burn} [kWh/a]	96.01	94.27	93.05	91.90	90.98	90.12	89.37
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	311.02	311.06	310.92	310.99	310.99	310.99	310.98
$W_{pump,DHW}$ [kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total} [kWh/a]	624.96	621.19	617.32	614.31	612.10	611.68	611.80
$Q_{pen,45}$ [kWh/a]	51.43	6.25	7.26	1.75	8.58	3.58	0.00
$Q_{pen,25}$ [kWh/a]	7902.42	7902.42	7902.42	7902.42	7902.42	7902.42	7902.42
$Q_{pen,20}$ [kWh/a]	0	0	0	0	0	0	0
$Q_{pen,red}$ [kWh/a]	51.43	6.25	7.26	1.75	8.58	3.58	0.00
FSC	0.634	0.707	0.781	0.851	0.892	0.921	0.936
$f_{sav,therm}$	0.438	0.499	0.544	0.584	0.621	0.654	0.684
$f_{sav,ext}$	0.420	0.472	0.509	0.543	0.574	0.602	0.627
f_{si}	0.417	0.471	0.509	0.543	0.573	0.602	0.627

Table 27: Results of MaxLean system simulations for the Climate Madrid with SFH100 with specific storage volume of 0.07 m^3/m^2

Building Climate	SFH60 Madrid						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	6300	7185	7515	7804	7804	7804	7804
E_{aux} [kWh/a]	3091	2495	2100	1840	1659	1542	1443
E_{ref} [kWh/a]	7804	7804	7804	7804	7804	7804	7804
E_{total} [kWh/a]	4425	3768	3342	3060	2867	2743	2642
$E_{total,ref}$ [kWh/a]	9997	9997	9997	9997	9997	9997	9997
$Q_{in,store}$ [kWh/a]	7646	7786	7909	7988	8037	8065	8092
$Q_{out,store}$ [kWh/a]	5998	5999	5999	5998	5999	5999	5999
$Q_{st,aux}$ [kWh/a]	2676	2122	1756	1516	1347	1238	1145
$Q_{st,coll}$ [kWh/a]	4969	5663	6153	6472	6690	6827	6947
$Q_{st,dhw}$ [kWh/a]	2977	2978	2978	2977	2977	2978	2978
$Q_{st,sh}$ [kWh/a]	3021	3021	3021	3021	3021	3021	3021
$W_{pump,sol}$ [kWh/a]	207.47	184.88	173.97	166.18	161.69	159.31	158.81
W_{burn} [kWh/a]	89.86	88.00	86.75	85.93	85.38	85.01	84.71
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	219.53	219.53	219.49	219.52	219.52	219.49	219.48
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	533.40	508.95	496.75	488.18	483.13	480.36	479.55
$Q_{pen,45}$ [kWh/a]	109.52	0.57	0.18	53.48	0.00	0.37	9.31
$Q_{pen,25}$ [kWh/a]	8027.14	8027.14	8027.14	8027.14	8027.14	8027.14	8027.14
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	109.42	0.47	0.08	53.38	-0.10	0.27	9.22
FSC	0.807	0.921	0.963	1.000	1.000	1.000	1.000
$f_{sav,therm}$	0.604	0.680	0.731	0.764	0.787	0.802	0.815
$f_{sav,ext}$	0.557	0.623	0.666	0.694	0.713	0.726	0.736
f_{si}	0.546	0.623	0.666	0.689	0.713	0.726	0.735

Table 28: Results of MaxLean system simulations for the Climate Madrid with SFH60 with 800 litres storage tank

Building Climate	SFH60 Madrid						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	6300	6876	7185	7350	7515	7679	7804
E_{aux} [kWh/a]	3404	2857	2446	2101	1834	1604	1406
E_{ref} [kWh/a]	7804	7804	7804	7804	7804	7804	7804
E_{total} [kWh/a]	4706	4146	3722	3370	3096	2863	2664
$E_{total,ref}$ [kWh/a]	9997	9997	9997	9997	9997	9997	9997
$Q_{in,store}$ [kWh/a]	7455	7641	7820	8003	8180	8360	8533
$Q_{out,store}$ [kWh/a]	5997	5998	5999	5999	5998	5998	5998
$Q_{st,aux}$ [kWh/a]	2977	2464	2076	1757	1507	1289	1111
$Q_{st,coll}$ [kWh/a]	4479	5178	5744	6246	6673	7071	7422
$Q_{st,dhw}$ [kWh/a]	2976	2977	2978	2978	2978	2978	2978
$Q_{st,sh}$ [kWh/a]	3021	3021	3021	3021	3021	3020	3021
$W_{pump,sol}$ [kWh/a]	193.81	190.42	186.60	184.55	182.81	182.37	182.31
W_{burn} [kWh/a]	90.75	89.08	87.85	86.79	85.99	85.29	84.70
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	219.57	219.54	219.53	219.49	219.49	219.50	219.48
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	520.67	515.58	510.52	507.38	504.84	503.71	503.04
$Q_{pen,45}$ [kWh/a]	216.32	13.39	0.70	1.18	11.25	7.73	3.44
$Q_{pen,25}$ [kWh/a]	8027.14	8027.14	8027.14	8027.14	8027.14	8027.14	8027.14
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	216.22	13.29	0.60	1.08	11.16	7.64	3.34
FSC	0.807	0.881	0.921	0.942	0.963	0.984	1.000
$f_{sav,therm}$	0.564	0.634	0.687	0.731	0.765	0.795	0.820
$f_{sav,ext}$	0.529	0.585	0.628	0.663	0.690	0.714	0.734
f_{si}	0.508	0.584	0.628	0.663	0.689	0.713	0.733

Table 29: Results of MaxLean system simulations for the Climate Madrid with SFH60 with specific storage volume of 0.07 m^3/m^2

Building Climate	SFH30 Madrid						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	5025	5341	5341	5341	5341	5341	5341
E_{aux} [kWh/a]	1284	954	798	688	624	577	531
E_{ref} [kWh/a]	5341	5341	5341	5341	5341	5341	5341
E_{total} [kWh/a]	2314	1917	1724	1591	1511	1456	1406
$E_{total,ref}$ [kWh/a]	7189	7189	7189	7189	7189	7189	7189
$Q_{in,store}$ [kWh/a]	5635	5802	5931	5999	6048	6072	6091
$Q_{out,store}$ [kWh/a]	3904	3903	3903	3904	3904	3904	3904
$Q_{st,aux}$ [kWh/a]	970	677	536	437	379	337	295
$Q_{st,coll}$ [kWh/a]	4665	5125	5394	5562	5669	5736	5796
$Q_{st,dhw}$ [kWh/a]	2978	2977	2977	2978	2977	2978	2978
$Q_{st,sh}$ [kWh/a]	926	926	926	926	926	926	926
$W_{pump,sol}$ [kWh/a]	199.85	174.37	160.35	151.06	145.30	142.03	140.41
W_{burn} [kWh/a]	84.33	83.30	82.81	82.46	82.25	82.10	81.95
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	111.04	111.02	111.03	111.03	111.03	111.03	111.03
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	411.77	385.24	370.73	361.09	355.13	351.70	349.94
$Q_{pen,45}$ [kWh/a]	8.98	3.39	147.34	1.50	0.00	0.00	0.00
$Q_{pen,25}$ [kWh/a]	7203.32	7203.32	7203.32	7203.32	7203.32	7203.32	7203.32
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	8.98	3.39	147.34	1.50	0.00	0.00	0.00
FSC	0.941	1.000	1.000	1.000	1.000	1.000	1.000
$f_{sav,therm}$	0.760	0.821	0.851	0.871	0.883	0.892	0.901
$f_{sav,ext}$	0.678	0.733	0.760	0.779	0.790	0.797	0.804
f_{si}	0.677	0.733	0.740	0.779	0.790	0.797	0.804

Table 30: Results of MaxLean system simulations for the Climate Madrid with SFH30 with 800 litres storage tank

Building Climate	SFH30 Madrid						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	5025	5190	5341	5341	5341	5341	5341
E_{aux} [kWh/a]	1477	1138	936	791	683	582	506
E_{ref} [kWh/a]	5341	5341	5341	5341	5341	5341	5341
E_{total} [kWh/a]	2478	2121	1902	1747	1630	1523	1444
$E_{total,ref}$ [kWh/a]	7189	7189	7189	7189	7189	7189	7189
$Q_{in,store}$ [kWh/a]	5414	5629	5843	6058	6257	6444	6618
$Q_{out,store}$ [kWh/a]	3903	3903	3904	3904	3904	3903	3904
$Q_{st,aux}$ [kWh/a]	1147	840	661	529	429	339	270
$Q_{st,coll}$ [kWh/a]	4267	4788	5182	5529	5828	6105	6347
$Q_{st,dhw}$ [kWh/a]	2977	2977	2978	2978	2978	2977	2978
$Q_{st,sh}$ [kWh/a]	926	926	926	926	926	926	926
$W_{pump,sol}$ [kWh/a]	187.68	181.61	175.89	171.96	168.79	166.89	165.70
W_{burn} [kWh/a]	84.90	83.86	83.25	82.79	82.45	82.15	81.92
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	111.02	111.05	111.01	111.03	111.03	111.02	111.02
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	400.15	393.06	386.69	382.31	378.82	376.60	375.18
$Q_{pen,45}$ [kWh/a]	70.69	11.44	2.56	0.01	54.82	149.97	15.87
$Q_{pen,25}$ [kWh/a]	7203.32	7203.32	7203.32	7203.32	7203.32	7203.32	7203.32
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	70.69	11.44	2.56	0.01	54.82	149.97	15.87
FSC	0.941	0.972	1.000	1.000	1.000	1.000	1.000
$f_{sav,therm}$	0.723	0.787	0.825	0.852	0.872	0.891	0.905
$f_{sav,ext}$	0.655	0.705	0.735	0.757	0.773	0.788	0.799
f_{si}	0.645	0.703	0.735	0.757	0.766	0.767	0.797

Table 31: Results of MaxLean system simulations for the Climate Madrid with SFH30 with specific storage volume of 0.07 m³/m²

Building Climate	SFH15 Madrid						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	4425	4425	4425	4425	4425	4425	4425
E_{aux} [kWh/a]	615	415	347	299	272	248	235
E_{ref} [kWh/a]	4425	4425	4425	4425	4425	4425	4425
E_{total} [kWh/a]	1431	1161	1053	979	937	903	885
$E_{total,ref}$ [kWh/a]	5909	5909	5909	5909	5909	5909	5909
$Q_{in,store}$ [kWh/a]	4895	5080	5199	5267	5313	5335	5357
$Q_{out,store}$ [kWh/a]	3124	3124	3124	3125	3125	3125	3125
$Q_{st,aux}$ [kWh/a]	351	184	124	83	61	41	30
$Q_{st,coll}$ [kWh/a]	4544	4896	5075	5184	5253	5294	5326
$Q_{st,dhw}$ [kWh/a]	2977	2977	2978	2978	2978	2978	2978
$Q_{st,sh}$ [kWh/a]	147	147	147	147	147	147	147
$W_{pump,sol}$ [kWh/a]	197.02	169.80	154.42	144.10	138.20	134.06	132.09
W_{burn} [kWh/a]	82.23	81.60	81.38	81.22	81.14	81.06	81.02
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	30.29	30.28	30.25	30.20	30.25	30.27	30.27
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	326.08	298.23	282.59	272.06	266.13	261.94	259.93
$Q_{pen,45}$ [kWh/a]	171.00	10.28	0.07	0.00	0.00	0.00	0.00
$Q_{pen,25}$ [kWh/a]	7210.15	7210.15	7210.15	7210.15	7210.15	7210.15	7210.15
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	175.62	14.90	4.69	4.63	4.63	4.63	4.63
FSC	1	1	1	1	1	1	1
$f_{sav,therm}$	0.861	0.906	0.922	0.932	0.939	0.944	0.947
$f_{sav,ext}$	0.758	0.804	0.822	0.834	0.841	0.847	0.850
f_{si}	0.728	0.801	0.821	0.834	0.841	0.846	0.849

Table 32: Results of MaxLean system simulations for the Climate Madrid with SFH15 with 800 litres storage tank

Building Climate		SFH15 Madrid					
A_{col}	[m²]	8	10	12	14	16	18	20
V_{Store}	[m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$	[kWh/a]	4425	4425	4425	4425	4425	4425	4425
E_{aux}	[kWh/a]	758	524	406	343	299	264	237
E_{ref}	[kWh/a]	4425	4425	4425	4425	4425	4425	4425
E_{total}	[kWh/a]	1546	1291	1155	1079	1025	983	951
$E_{total,ref}$	[kWh/a]	5909	5909	5909	5909	5909	5909	5909
$Q_{in,store}$	[kWh/a]	4656	4894	5124	5346	5552	5736	5909
$Q_{out,store}$	[kWh/a]	3123	3123	3125	3125	3125	3125	3125
$Q_{st,aux}$	[kWh/a]	474	275	176	121	83	54	32
$Q_{st,coll}$	[kWh/a]	4182	4619	4948	5226	5470	5682	5877
$Q_{st,dhw}$	[kWh/a]	2976	2976	2978	2978	2978	2978	2978
$Q_{st,sh}$	[kWh/a]	147	147	147	147	147	147	147
$W_{pump,sol}$	[kWh/a]	185.71	178.10	171.23	166.44	162.45	159.72	157.71
W_{burn}	[kWh/a]	82.64	81.94	81.57	81.37	81.23	81.12	81.04
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	30.28	30.28	30.28	30.20	30.27	30.26	30.26
$W_{pump,DHW}$	[kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total}	[kWh/a]	315.16	306.85	299.63	294.56	290.50	287.65	285.55
$Q_{pen,45}$	[kWh/a]	156.96	136.10	21.01	4.43	9.80	5.85	0.01
$Q_{pen,25}$	[kWh/a]	7210.15	7210.15	7210.15	7210.15	7210.15	7210.15	7210.15
$Q_{pen,20}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$	[kWh/a]	161.58	140.73	25.64	9.05	14.43	10.48	4.64
FSC		1	1	1	1	1	1	1
$f_{sav,therm}$		0.829	0.882	0.908	0.923	0.932	0.940	0.946
$f_{sav,ext}$		0.738	0.781	0.805	0.817	0.827	0.834	0.839
f_{si}		0.711	0.758	0.800	0.816	0.824	0.832	0.838

Table 33: Results of MaxLean system simulations for the Climate Madrid with SFH15 with specific storage volume of 0.07 m^3/m^2

Building Climate	SFH100 Zurich						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	6292	8338	10131	11439	12547	13363	14179
E_{aux} [kWh/a]	16452	15610	15010	14591	14257	14003	13781
E_{ref} [kWh/a]	20914	20914	20914	20914	20914	20914	20914
E_{total} [kWh/a]	18499	17622	17002	16568	16228	15970	15749
$E_{total,ref}$ [kWh/a]	22719	22719	22719	22719	22719	22719	22719
$Q_{in,store}$ [kWh/a]	18495	18605	18675	18719	18756	18776	18798
$Q_{out,store}$ [kWh/a]	17152	17152	17152	17152	17152	17152	17152
$Q_{st,aux}$ [kWh/a]	14862	14098	13548	13163	12854	12622	12415
$Q_{st,coll}$ [kWh/a]	3633	4506	5128	5556	5901	6154	6382
$Q_{st,dhw}$ [kWh/a]	3047	3047	3047	3047	3047	3047	3047
$Q_{st,sh}$ [kWh/a]	14105	14105	14105	14105	14104	14105	14104
$W_{pump,sol}$ [kWh/a]	187.27	174.86	168.29	163.10	161.21	160.28	161.16
W_{burn} [kWh/a]	115.81	114.12	112.85	111.97	111.24	110.70	110.21
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	499.07	499.05	499.08	499.07	499.09	499.07	499.07
$W_{pump,DHW}$ [kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total} [kWh/a]	818.95	804.84	797.01	790.94	788.34	786.84	787.25
$Q_{pen,45}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,25}$ [kWh/a]	51.90	51.90	51.90	51.90	51.90	51.90	51.90
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	0	0	0	0	0	0	0
FSC	0.301	0.399	0.484	0.547	0.600	0.639	0.678
$f_{sav,therm}$	0.213	0.254	0.282	0.302	0.318	0.330	0.341
$f_{sav,ext}$	0.186	0.224	0.252	0.271	0.286	0.297	0.307
f_{si}	0.186	0.224	0.252	0.271	0.286	0.297	0.307

Table 34: Results of MaxLean system simulations for the Climate Zurich with SFH100 with 800 litres storage tank

Building Climate	SFH100 Zurich						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	6292	7315	8338	9340	10131	10820	11439
E_{aux} [kWh/a]	16523	15788	15247	14756	14313	13908	13542
E_{ref} [kWh/a]	20914	20914	20914	20914	20914	20914	20914
E_{total} [kWh/a]	18540	17810	17266	16775	16332	15927	15563
$E_{total,ref}$ [kWh/a]	22719	22719	22719	22719	22719	22719	22719
$Q_{in,store}$ [kWh/a]	18378	18455	18561	18660	18767	18868	18979
$Q_{out,store}$ [kWh/a]	17143	17153	17153	17151	17151	17145	17144
$Q_{st,aux}$ [kWh/a]	15122	14431	13924	13460	13042	12659	12319
$Q_{st,coll}$ [kWh/a]	3256	4024	4637	5200	5725	6209	6661
$Q_{st,dhw}$ [kWh/a]	3047	3047	3047	3047	3047	3047	3047
$Q_{st,sh}$ [kWh/a]	14096	14106	14106	14104	14103	14098	14097
$W_{pump,sol}$ [kWh/a]	174.71	177.96	178.10	178.95	179.79	180.95	182.52
W_{burn} [kWh/a]	116.37	114.73	113.65	112.53	111.64	110.73	109.97
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	499.12	499.12	499.11	499.12	499.11	499.10	499.10
$W_{pump,DHW}$ [kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total} [kWh/a]	807.00	808.60	807.66	807.39	807.34	807.59	808.38
$Q_{pen,45}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,25}$ [kWh/a]	51.90	51.90	51.90	51.90	51.90	51.90	51.90
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	0	0	0	0	0	0	0
FSC	0.301	0.350	0.399	0.447	0.484	0.517	0.547
$f_{sav,therm}$	0.210	0.245	0.271	0.294	0.316	0.335	0.352
$f_{sav,ext}$	0.184	0.216	0.240	0.262	0.281	0.299	0.315
f_{si}	0.184	0.216	0.240	0.262	0.281	0.299	0.315

Table 35: Results of MaxLean system simulations for the Climate Zurich with SFH100 with specific storage volume of 0.07 m³/m²

Building Climate	SFH60 Zurich						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	5699	7223	8379	9195	10011	10827	11574
E_{aux} [kWh/a]	9857	9235	8771	8417	8146	7911	7722
E_{ref} [kWh/a]	14312	14312	14312	14312	14312	14312	14312
E_{total} [kWh/a]	11698	11030	10543	10173	9893	9657	9468
$E_{total,ref}$ [kWh/a]	15972	15972	15972	15972	15972	15972	15972
$Q_{in,store}$ [kWh/a]	12753	12891	12975	13035	13078	13108	13133
$Q_{out,store}$ [kWh/a]	11531	11532	11531	11532	11532	11532	11532
$Q_{st,aux}$ [kWh/a]	9161	8570	8127	7790	7530	7308	7128
$Q_{st,coll}$ [kWh/a]	3593	4322	4848	5245	5548	5800	6005
$Q_{st,dhw}$ [kWh/a]	3047	3047	3047	3047	3047	3047	3047
$Q_{st,sh}$ [kWh/a]	8485	8485	8485	8485	8485	8485	8485
$W_{pump,sol}$ [kWh/a]	185.69	169.42	161.26	156.09	153.79	153.69	154.27
W_{burn} [kWh/a]	110.32	108.42	106.99	105.88	105.04	104.31	103.72
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	423.72	423.72	423.71	423.72	423.72	423.71	423.72
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	736.28	718.11	708.50	702.23	699.09	698.25	698.25
$Q_{pen,45}$ [kWh/a]	10.85	10.89	89.80	4.57	5.44	5.95	1.68
$Q_{pen,25}$ [kWh/a]	92.60	92.60	92.60	92.60	92.60	92.60	92.60
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	10.84	10.88	89.79	4.56	5.44	5.94	1.67
FSC	0.398	0.505	0.585	0.642	0.699	0.756	0.809
$f_{sav,therm}$	0.311	0.355	0.387	0.412	0.431	0.447	0.460
$f_{sav,ext}$	0.268	0.309	0.340	0.363	0.381	0.395	0.407
f_{si}	0.267	0.309	0.334	0.363	0.380	0.395	0.407

Table 36: Results of MaxLean system simulations for the Climate Zurich with SFH60 with 800 litres storage tank

Building Climate	SFH60 Zurich						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	5699	6579	7223	7841	8379	8787	9195
E_{aux} [kWh/a]	10190	9608	9198	8802	8463	8150	7857
E_{ref} [kWh/a]	14312	14312	14312	14312	14312	14312	14312
E_{total} [kWh/a]	12000	11414	10997	10597	10256	9944	9651
$E_{total,ref}$ [kWh/a]	15972	15972	15972	15972	15972	15972	15972
$Q_{in,store}$ [kWh/a]	12681	12784	12912	13026	13147	13256	13376
$Q_{out,store}$ [kWh/a]	11530	11531	11531	11531	11531	11526	11528
$Q_{st,aux}$ [kWh/a]	9478	8928	8532	8155	7826	7526	7247
$Q_{st,coll}$ [kWh/a]	3203	3856	4380	4871	5321	5731	6130
$Q_{st,dhw}$ [kWh/a]	3045	3046	3047	3047	3047	3046	3046
$Q_{st,sh}$ [kWh/a]	8485	8485	8485	8485	8484	8480	8482
$W_{pump,sol}$ [kWh/a]	172.30	172.36	170.87	170.64	171.12	171.86	172.91
W_{burn} [kWh/a]	111.29	109.50	108.34	107.09	106.09	105.19	104.33
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	423.72	423.71	423.71	423.71	423.72	423.72	423.71
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	723.85	722.12	719.47	717.97	717.48	717.31	717.50
$Q_{pen,45}$ [kWh/a]	119.00	125.01	14.76	11.32	62.43	98.35	106.29
$Q_{pen,25}$ [kWh/a]	92.60	92.60	92.60	92.60	92.60	92.60	92.60
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	118.99	125.00	14.76	11.31	62.42	98.34	106.28
FSC	0.398	0.460	0.505	0.548	0.585	0.614	0.642
$f_{sav,therm}$	0.288	0.329	0.357	0.385	0.409	0.431	0.451
$f_{sav,ext}$	0.249	0.285	0.311	0.337	0.358	0.377	0.396
f_{si}	0.241	0.278	0.311	0.336	0.354	0.371	0.389

Table 37: Results of MaxLean system simulations for the Climate Zurich with SFH60 with specific storage volume of 0.07 m^3/m^2

Building Climate	SFH30 Zurich						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	4966	5884	6700	7456	7994	8391	8742
E_{aux} [kWh/a]	5649	5184	4837	4581	4387	4211	4070
E_{ref} [kWh/a]	9227	9227	9227	9227	9227	9227	9227
E_{total} [kWh/a]	7220	6707	6333	6060	5857	5678	5537
$E_{total,ref}$ [kWh/a]	10643	10643	10643	10643	10643	10643	10643
$Q_{in,store}$ [kWh/a]	8490	8639	8728	8792	8838	8870	8903
$Q_{out,store}$ [kWh/a]	7207	7207	7208	7208	7208	7208	7208
$Q_{st,aux}$ [kWh/a]	5072	4637	4315	4076	3894	3731	3600
$Q_{st,coll}$ [kWh/a]	3418	4002	4412	4716	4944	5138	5303
$Q_{st,dhw}$ [kWh/a]	3046	3046	3047	3047	3047	3047	3047
$Q_{st,sh}$ [kWh/a]	4161	4161	4161	4161	4161	4161	4161
$W_{pump,sol}$ [kWh/a]	178.90	161.20	151.49	145.47	142.74	141.98	142.08
W_{burn} [kWh/a]	97.82	96.39	95.29	94.48	93.86	93.32	92.87
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	335.07	335.11	335.08	335.05	335.07	335.04	335.07
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	628.34	609.23	598.40	591.54	588.22	586.89	586.56
$Q_{pen,45}$ [kWh/a]	118.30	215.48	2.04	119.30	8.50	0.24	158.77
$Q_{pen,25}$ [kWh/a]	285.03	285.03	285.03	285.03	285.03	285.03	285.03
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	118.30	215.48	2.04	119.30	8.50	0.24	158.77
FSC	0.538	0.638	0.726	0.808	0.866	0.909	0.947
$f_{sav,therm}$	0.388	0.438	0.476	0.504	0.525	0.544	0.559
$f_{sav,ext}$	0.322	0.370	0.405	0.431	0.450	0.466	0.480
f_{si}	0.310	0.350	0.405	0.419	0.449	0.466	0.465

Table 38: Results of MaxLean system simulations for the Climate Zurich with SFH30 with 800 litres storage tank

Building Climate		SFH30 Zurich					
A_{col}	[m²]	8	10	12	14	16	18	20
V_{Store}	[m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$	[kWh/a]	4966	5476	5884	6292	6700	7108	7456
E_{aux}	[kWh/a]	5918	5459	5144	4855	4601	4363	4142
E_{ref}	[kWh/a]	9227	9227	9227	9227	9227	9227	9227
E_{total}	[kWh/a]	7459	6994	6671	6376	6119	5879	5657
$E_{total,ref}$	[kWh/a]	10643	10643	10643	10643	10643	10643	10643
$Q_{in,store}$	[kWh/a]	8394	8523	8664	8793	8926	9052	9180
$Q_{out,store}$	[kWh/a]	7205	7207	7208	7208	7208	7206	7207
$Q_{st,aux}$	[kWh/a]	5332	4899	4598	4325	4082	3857	3652
$Q_{st,coll}$	[kWh/a]	3062	3624	4066	4468	4844	5195	5528
$Q_{st,dhw}$	[kWh/a]	3044	3046	3047	3047	3047	3046	3047
$Q_{st,sh}$	[kWh/a]	4161	4161	4161	4161	4161	4160	4160
$W_{pump,sol}$	[kWh/a]	166.29	165.05	162.72	161.38	160.82	161.03	161.08
W_{burn}	[kWh/a]	98.59	97.18	96.28	95.37	94.61	93.90	93.27
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	335.10	335.08	335.08	335.08	335.07	335.04	335.05
$W_{pump,DHW}$	[kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total}	[kWh/a]	616.52	613.86	610.63	608.38	607.05	606.51	605.94
$Q_{pen,45}$	[kWh/a]	366.61	22.82	9.08	50.37	29.91	54.59	52.01
$Q_{pen,25}$	[kWh/a]	285.03	285.03	285.03	285.03	285.03	285.03	285.03
$Q_{pen,20}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$	[kWh/a]	366.61	22.82	9.08	50.37	29.91	54.59	52.01
FSC		0.538	0.593	0.638	0.682	0.726	0.770	0.808
$f_{sav,therm}$		0.359	0.408	0.442	0.474	0.501	0.527	0.551
$f_{sav,ext}$		0.299	0.343	0.373	0.401	0.425	0.448	0.468
f_{si}		0.265	0.341	0.372	0.396	0.422	0.442	0.464

Table 39: Results of MaxLean system simulations for the Climate Zurich with SFH30 with specific storage volume of 0.07 m^3/m^2

Building Climate	SFH15 Zurich						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	4393	5209	5799	6166	6517	6732	6735
E_{aux} [kWh/a]	3601	3218	2951	2765	2617	2502	2412
E_{ref} [kWh/a]	6735	6735	6735	6735	6735	6735	6735
E_{total} [kWh/a]	4933	4498	4201	3998	3839	3720	3627
$E_{total,ref}$ [kWh/a]	7921	7921	7921	7921	7921	7921	7921
$Q_{in,store}$ [kWh/a]	6414	6572	6666	6734	6785	6823	6852
$Q_{out,store}$ [kWh/a]	5089	5088	5089	5089	5090	5089	5089
$Q_{st,aux}$ [kWh/a]	3099	2751	2510	2342	2208	2104	2021
$Q_{st,coll}$ [kWh/a]	3315	3821	4156	4392	4577	4719	4831
$Q_{st,dhw}$ [kWh/a]	3047	3046	3047	3047	3047	3047	3047
$Q_{st,sh}$ [kWh/a]	2042	2042	2042	2042	2042	2042	2042
$W_{pump,sol}$ [kWh/a]	174.97	155.74	144.62	137.99	134.44	133.17	132.30
W_{burn} [kWh/a]	91.59	90.40	89.54	88.96	88.50	88.13	87.84
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	249.47	249.48	249.48	249.45	249.50	249.50	249.41
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	532.58	512.18	500.19	492.94	488.98	487.34	486.10
$Q_{pen,45}$ [kWh/a]	14.97	262.72	29.00	0.38	0.35	0.15	0.09
$Q_{pen,25}$ [kWh/a]	285.46	285.46	285.46	285.46	285.46	285.46	285.46
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	14.95	262.69	28.98	0.35	0.32	0.13	0.06
FSC	0.652	0.773	0.861	0.916	0.968	1.000	1.000
$f_{sav,therm}$	0.465	0.522	0.562	0.589	0.611	0.628	0.642
$f_{sav,ext}$	0.377	0.432	0.470	0.495	0.515	0.530	0.542
f_{si}	0.375	0.399	0.466	0.495	0.515	0.530	0.542

Table 40: Results of MaxLean system simulations for the Climate Zurich with SFH15 with 800 litres storage tank

Building Climate	SFH15 Zurich						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	4393	4801	5209	5530	5799	5990	6166
E_{aux} [kWh/a]	3837	3445	3187	2975	2794	2616	2465
E_{ref} [kWh/a]	6735	6735	6735	6735	6735	6735	6735
E_{total} [kWh/a]	5140	4739	4471	4251	4064	3882	3730
$E_{total,ref}$ [kWh/a]	7921	7921	7921	7921	7921	7921	7921
$Q_{in,store}$ [kWh/a]	6298	6444	6599	6746	6893	7030	7170
$Q_{out,store}$ [kWh/a]	5088	5089	5089	5089	5089	5088	5089
$Q_{st,aux}$ [kWh/a]	3324	2960	2723	2526	2356	2192	2055
$Q_{st,coll}$ [kWh/a]	2974	3484	3876	4220	4537	4838	5115
$Q_{st,dhw}$ [kWh/a]	3045	3047	3047	3046	3046	3046	3047
$Q_{st,sh}$ [kWh/a]	2042	2042	2042	2042	2042	2042	2042
$W_{pump,sol}$ [kWh/a]	162.82	160.43	157.08	154.56	152.99	152.28	151.88
W_{burn} [kWh/a]	92.30	91.05	90.32	89.60	89.06	88.52	88.13
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	249.46	249.51	249.45	249.43	249.48	249.42	249.46
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	521.12	517.54	513.39	510.13	508.08	506.77	506.02
$Q_{pen,45}$ [kWh/a]	90.71	13.30	45.68	154.96	75.96	73.94	19.86
$Q_{pen,25}$ [kWh/a]	285.46	285.46	285.46	285.46	285.46	285.46	285.46
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	90.69	13.28	45.65	154.94	75.94	73.91	19.84
FSC	0.652	0.713	0.773	0.821	0.861	0.889	0.916
$f_{sav,therm}$	0.430	0.488	0.527	0.558	0.585	0.612	0.634
$f_{sav,ext}$	0.351	0.402	0.436	0.463	0.487	0.510	0.529
f_{si}	0.340	0.400	0.430	0.444	0.477	0.500	0.527

Table 41: Results of MaxLean system simulations for the Climate Zurich with SFH15 with specific storage volume of 0.07 m^3/m^2

Building Climate		SFH100 Stockholm						
A_{col}	[m²]	8	12	16	20	24	28	32
V_{Store}	[m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$	[kWh/a]	6492	8410	10237	11655	12947	14238	15391
E_{aux}	[kWh/a]	22404	21569	20933	20465	20105	19840	19619
E_{ref}	[kWh/a]	27646	27646	27646	27646	27646	27646	27646
E_{total}	[kWh/a]	24544	23679	23027	22548	22184	21917	21697
$E_{total,ref}$	[kWh/a]	29601	29601	29601	29601	29601	29601	29601
$Q_{in,store}$	[kWh/a]	24102	24205	24269	24316	24351	24370	24391
$Q_{out,store}$	[kWh/a]	22809	22809	22809	22809	22809	22809	22809
$Q_{st,aux}$	[kWh/a]	20502	19730	19141	18704	18370	18125	17917
$Q_{st,coll}$	[kWh/a]	3600	4476	5128	5611	5980	6246	6473
$Q_{st,dhw}$	[kWh/a]	3129	3129	3129	3129	3129	3129	3129
$Q_{st,sh}$	[kWh/a]	19680	19680	19680	19680	19680	19680	19680
$W_{pump,sol}$	[kWh/a]	175.23	165.04	159.91	156.73	155.88	155.38	156.50
W_{burn}	[kWh/a]	127.90	126.15	124.85	123.87	123.10	122.54	122.08
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	535.98	535.98	535.98	535.98	535.98	535.98	535.98
$W_{pump,DHW}$	[kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total}	[kWh/a]	855.91	843.97	837.54	833.38	831.76	830.70	831.37
$Q_{pen,45}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,25}$	[kWh/a]	6.15	6.15	6.15	6.15	6.15	6.15	6.15
$Q_{pen,20}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FSC		0.235	0.304	0.370	0.422	0.468	0.515	0.557
$f_{sav,therm}$		0.190	0.220	0.243	0.260	0.273	0.282	0.290
$f_{sav,ext}$		0.171	0.200	0.222	0.238	0.251	0.260	0.267
f_{si}		0.171	0.200	0.222	0.238	0.251	0.260	0.267

Table 42: Results of MaxLean system simulations for the Climate Stockholm with SFH100 with 800 litres storage tank

Building Climate	SFH100 Stockholm						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	6492	7496	8410	9323	10237	11010	11655
E_{aux} [kWh/a]	22450	21709	21140	20594	20109	19627	19207
E_{ref} [kWh/a]	27646	27646	27646	27646	27646	27646	27646
E_{total} [kWh/a]	24568	23831	23261	22713	22232	21752	21335
$E_{total,ref}$ [kWh/a]	29601	29601	29601	29601	29601	29601	29601
$Q_{in,store}$ [kWh/a]	24057	24120	24201	24287	24381	24459	24560
$Q_{out,store}$ [kWh/a]	22867	22874	22874	22877	22877	22867	22872
$Q_{st,aux}$ [kWh/a]	20793	20094	19551	19042	18578	18123	17739
$Q_{st,coll}$ [kWh/a]	3263	4026	4651	5245	5804	6336	6821
$Q_{st,dhw}$ [kWh/a]	3129	3129	3129	3129	3129	3129	3129
$Q_{st,sh}$ [kWh/a]	19739	19745	19744	19748	19748	19738	19743
$W_{pump,sol}$ [kWh/a]	165.53	168.67	169.09	170.17	172.38	174.27	176.59
W_{burn} [kWh/a]	128.47	126.85	125.71	124.44	123.46	122.35	121.44
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	536.46	536.47	536.47	536.46	536.45	536.45	536.45
$W_{pump,DHW}$ [kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total} [kWh/a]	847.26	848.79	848.08	847.87	849.09	849.88	851.28
$Q_{pen,45}$ [kWh/a]	0.95	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,25}$ [kWh/a]	6.15	6.15	6.15	6.15	6.15	6.15	6.15
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	0.95	0.00	0.00	0.00	0.00	0.00	0.00
FSC	0.235	0.271	0.304	0.337	0.370	0.398	0.422
$f_{sav,therm}$	0.188	0.215	0.235	0.255	0.273	0.290	0.305
$f_{sav,ext}$	0.170	0.195	0.214	0.233	0.249	0.265	0.279
f_{si}	0.170	0.195	0.214	0.233	0.249	0.265	0.279

Table 43: Results of MaxLean system simulations for the Climate Stockholm with SFH100 with specific storage volume of 0.07 m^3/m^2

Building Climate		SFH60 Stockholm						
A_{col}	[m²]	8	12	16	20	24	28	32
V_{Store}	[m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$	[kWh/a]	5683	7388	8679	9939	10810	11383	11956
E_{aux}	[kWh/a]	14306	13604	13090	12702	12410	12169	11955
E_{ref}	[kWh/a]	19150	19150	19150	19150	19150	19150	19150
E_{total}	[kWh/a]	16263	15530	14998	14597	14300	14057	13844
$E_{total,ref}$	[kWh/a]	20876	20876	20876	20876	20876	20876	20876
$Q_{in,store}$	[kWh/a]	16805	16939	17022	17071	17109	17135	17160
$Q_{out,store}$	[kWh/a]	15648	15648	15648	15648	15648	15649	15648
$Q_{st,aux}$	[kWh/a]	13254	12592	12105	11737	11457	11228	11026
$Q_{st,coll}$	[kWh/a]	3552	4347	4917	5334	5652	5907	6134
$Q_{st,dhw}$	[kWh/a]	3128	3129	3129	3129	3129	3129	3129
$Q_{st,sh}$	[kWh/a]	12519	12520	12520	12520	12519	12519	12519
$W_{pump,sol}$	[kWh/a]	173.30	162.03	156.19	151.65	150.14	149.86	150.96
W_{burn}	[kWh/a]	112.57	111.07	109.94	109.10	108.44	107.91	107.42
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	480.44	480.45	480.45	480.45	480.44	480.43	480.44
$W_{pump,DHW}$	[kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total}	[kWh/a]	783.12	770.35	763.38	757.99	755.83	755.00	755.63
$Q_{pen,45}$	[kWh/a]	54.48	32.50	1.20	27.19	32.91	1.18	0.13
$Q_{pen,25}$	[kWh/a]	8.82	8.82	8.82	8.82	8.82	8.82	8.82
$Q_{pen,20}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$	[kWh/a]	54.48	32.50	1.20	27.19	32.91	1.18	0.13
FSC		0.297	0.386	0.453	0.519	0.565	0.594	0.624
$f_{sav,therm}$		0.253	0.290	0.316	0.337	0.352	0.365	0.376
$f_{sav,ext}$		0.221	0.256	0.282	0.301	0.315	0.327	0.337
f_{si}		0.218	0.255	0.281	0.299	0.313	0.327	0.337

Table 44: Results of MaxLean system simulations for the Climate Stockholm with SFH60 with 800 litres storage tank

Building Climate	SFH60 Stockholm						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	5683	6597	7388	8033	8679	9325	9939
E_{aux} [kWh/a]	14621	14010	13556	13129	12765	12425	12106
E_{ref} [kWh/a]	19150	19150	19150	19150	19150	19150	19150
E_{total} [kWh/a]	16553	15942	15485	15057	14694	14354	14037
$E_{total,ref}$ [kWh/a]	20876	20876	20876	20876	20876	20876	20876
$Q_{in,store}$ [kWh/a]	16754	16843	16952	17056	17161	17263	17369
$Q_{out,store}$ [kWh/a]	15644	15643	15649	15648	15644	15642	15643
$Q_{st,aux}$ [kWh/a]	13555	12979	12544	12144	11797	11472	11177
$Q_{st,coll}$ [kWh/a]	3198	3864	4408	4912	5364	5791	6192
$Q_{st,dhw}$ [kWh/a]	3128	3128	3129	3129	3129	3129	3129
$Q_{st,sh}$ [kWh/a]	12515	12516	12519	12519	12515	12514	12515
$W_{pump,sol}$ [kWh/a]	162.26	163.76	163.39	163.94	164.90	165.88	167.16
W_{burn} [kWh/a]	113.32	111.90	110.98	109.97	109.21	108.47	107.76
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	480.46	480.46	480.44	480.45	480.43	480.44	480.46
$W_{pump,DHW}$ [kWh/a]	8.04	8.04	8.04	8.04	8.04	8.04	8.04
W_{total} [kWh/a]	772.84	772.92	771.61	771.15	771.34	771.59	772.18
$Q_{pen,45}$ [kWh/a]	9.17	275.23	1.96	19.65	25.49	38.93	23.20
$Q_{pen,25}$ [kWh/a]	8.82	8.82	8.82	8.82	8.82	8.82	8.82
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	9.17	275.23	1.96	19.65	25.49	38.93	23.20
FSC	0.297	0.344	0.386	0.420	0.453	0.487	0.519
$f_{sav,therm}$	0.236	0.268	0.292	0.314	0.333	0.351	0.368
$f_{sav,ext}$	0.207	0.236	0.258	0.279	0.296	0.312	0.328
f_{si}	0.207	0.223	0.258	0.278	0.295	0.311	0.326

Table 45: Results of MaxLean system simulations for the Climate Zurich with SFH60 with specific storage volume of 0.07 m^3/m^2

Building Climate		SFH30 Stockholm						
A_{col}	[m²]	8	12	16	20	24	28	32
V_{Store}	[m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$	[kWh/a]	4917	6147	6880	7454	8027	8600	9156
E_{aux}	[kWh/a]	8232	7755	7414	7153	6958	6804	6670
E_{ref}	[kWh/a]	12086	12086	12086	12086	12086	12086	12086
E_{total}	[kWh/a]	9937	9418	9053	8776	8574	8416	8282
$E_{total,ref}$	[kWh/a]	13614	13614	13614	13614	13614	13614	13614
$Q_{in,store}$	[kWh/a]	10872	11013	11098	11149	11191	11223	11252
$Q_{out,store}$	[kWh/a]	9639	9638	9638	9638	9638	9638	9638
$Q_{st,aux}$	[kWh/a]	7547	7098	6780	6535	6354	6207	6083
$Q_{st,coll}$	[kWh/a]	3324	3915	4317	4614	4837	5016	5169
$Q_{st,dhw}$	[kWh/a]	3129	3129	3129	3129	3129	3129	3129
$Q_{st,sh}$	[kWh/a]	6509	6509	6509	6509	6509	6509	6509
$W_{pump,sol}$	[kWh/a]	166.93	151.63	143.44	137.81	135.17	134.05	134.33
W_{burn}	[kWh/a]	104.74	103.35	102.35	101.55	100.99	100.52	100.12
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	393.55	393.54	393.54	393.54	393.55	393.54	393.53
$W_{pump,DHW}$	[kWh/a]	7.80	7.80	7.80	7.80	7.80	7.80	7.80
W_{total}	[kWh/a]	681.79	665.09	655.89	649.47	646.27	644.67	644.54
$Q_{pen,45}$	[kWh/a]	5.67	13.65	4.04	3.60	2.82	3.99	16.41
$Q_{pen,25}$	[kWh/a]	29.65	29.65	29.65	29.65	29.65	29.65	29.65
$Q_{pen,20}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$	[kWh/a]	5.63	13.61	4.01	3.57	2.79	3.95	16.38
FSC		0.407	0.509	0.569	0.617	0.664	0.712	0.758
$f_{sav,therm}$		0.319	0.358	0.387	0.408	0.424	0.437	0.448
$f_{sav,ext}$		0.270	0.308	0.335	0.355	0.370	0.382	0.392
f_{si}		0.270	0.307	0.335	0.355	0.370	0.382	0.390

Table 46: Results of MaxLean system simulations for the Climate Stockholm with SFH30 with 800 litres storage tank

Building Climate		SFH30 Stockholm						
A_{col}	[m²]	8	10	12	14	16	18	20
V_{Store}	[m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$	[kWh/a]	4917	5563	6147	6594	6880	7167	7454
E_{aux}	[kWh/a]	8484	8038	7722	7436	7188	6954	6755
E_{ref}	[kWh/a]	12086	12086	12086	12086	12086	12086	12086
E_{total}	[kWh/a]	10162	9711	9388	9097	8847	8613	8412
$E_{total,ref}$	[kWh/a]	13614	13614	13614	13614	13614	13614	13614
$Q_{in,store}$	[kWh/a]	10797	10913	11035	11149	11272	11392	11505
$Q_{out,store}$	[kWh/a]	9637	9638	9638	9638	9638	9635	9636
$Q_{st,aux}$	[kWh/a]	7788	7370	7065	6799	6561	6341	6155
$Q_{st,coll}$	[kWh/a]	3009	3544	3970	4349	4710	5051	5350
$Q_{st,dhw}$	[kWh/a]	3128	3129	3129	3129	3129	3129	3129
$Q_{st,sh}$	[kWh/a]	6510	6509	6509	6509	6508	6506	6508
$W_{pump,sol}$	[kWh/a]	155.75	155.09	153.04	151.82	151.85	152.09	151.98
W_{burn}	[kWh/a]	105.48	104.11	103.25	102.37	101.67	101.00	100.45
W_{contr}	[kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$	[kWh/a]	393.54	393.53	393.55	393.54	393.55	393.56	393.53
$W_{pump,DHW}$	[kWh/a]	7.80	7.80	7.80	7.80	7.80	7.80	7.80
W_{total}	[kWh/a]	671.34	669.29	666.40	664.29	663.63	663.22	662.52
$Q_{pen,45}$	[kWh/a]	200.27	39.23	8.38	5.35	0.02	5.35	29.72
$Q_{pen,25}$	[kWh/a]	29.65	29.65	29.65	29.65	29.65	29.65	29.65
$Q_{pen,20}$	[kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$	[kWh/a]	200.23	39.20	8.34	5.32	-0.01	5.32	29.68
FSC		0.407	0.460	0.509	0.546	0.569	0.593	0.617
$f_{sav,therm}$		0.298	0.335	0.361	0.385	0.405	0.425	0.441
$f_{sav,ext}$		0.254	0.287	0.310	0.332	0.350	0.367	0.382
f_{si}		0.239	0.284	0.310	0.331	0.350	0.367	0.380

Table 47: Results of MaxLean system simulations for the Climate Zurich with SFH30 with specific storage volume of 0.07 m^3/m^2

Building Climate	SFH15 Stockholm						
A_{col} [m²]	8	12	16	20	24	28	32
V_{Store} [m³]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
$Q_{solar,usable,heat}$ [kWh/a]	4449	5071	5644	6217	6653	6987	7193
E_{aux} [kWh/a]	5348	4982	4740	4586	4449	4342	4247
E_{ref} [kWh/a]	8618	8618	8618	8618	8618	8618	8618
E_{total} [kWh/a]	6830	6419	6151	5980	5834	5722	5625
$E_{total,ref}$ [kWh/a]	9933	9933	9933	9933	9933	9933	9933
$Q_{in,store}$ [kWh/a]	7968	8122	8212	8270	8317	8346	8375
$Q_{out,store}$ [kWh/a]	6689	6690	6690	6690	6690	6690	6690
$Q_{st,aux}$ [kWh/a]	4774	4443	4221	4075	3948	3850	3763
$Q_{st,coll}$ [kWh/a]	3193	3679	3992	4195	4368	4496	4612
$Q_{st,dhw}$ [kWh/a]	3128	3129	3129	3129	3129	3129	3129
$Q_{st,sh}$ [kWh/a]	3561	3561	3561	3561	3561	3561	3561
$W_{pump,sol}$ [kWh/a]	162.18	145.05	135.49	129.09	125.99	123.93	123.72
W_{burn} [kWh/a]	96.86	95.75	95.01	94.52	94.11	93.77	93.47
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	317.41	317.44	317.44	317.44	317.45	317.45	317.45
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	592.99	574.78	564.48	557.60	554.10	551.69	551.18
$Q_{pen,45}$ [kWh/a]	152.25	99.85	28.38	26.17	18.68	16.71	15.10
$Q_{pen,25}$ [kWh/a]	29.81	29.81	29.81	29.81	29.81	29.81	29.81
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	152.17	99.76	28.29	26.08	18.59	16.62	15.01
FSC	0.516	0.588	0.655	0.721	0.772	0.811	0.835
$f_{sav,therm}$	0.379	0.422	0.450	0.468	0.484	0.496	0.507
$f_{sav,ext}$	0.312	0.354	0.381	0.398	0.413	0.424	0.434
f_{si}	0.297	0.344	0.378	0.395	0.411	0.422	0.432

Table 48: Results of MaxLean system simulations for the Climate Stockholm with SFH15 with 800 litres storage tank

Building Climate	SFH15 Stockholm						
A_{col} [m²]	8	10	12	14	16	18	20
V_{Store} [m³]	0.56	0.7	0.84	0.98	1.12	1.26	1.4
$Q_{solar,usable,heat}$ [kWh/a]	4449	4784	5071	5357	5644	5930	6217
E_{aux} [kWh/a]	5553	5194	4971	4766	4602	4456	4331
E_{ref} [kWh/a]	8618	8618	8618	8618	8618	8618	8618
E_{total} [kWh/a]	7011	6644	6411	6199	6032	5884	5756
$E_{total,ref}$ [kWh/a]	9933	9933	9933	9933	9933	9933	9933
$Q_{in,store}$ [kWh/a]	7877	8011	8150	8282	8417	8551	8670
$Q_{out,store}$ [kWh/a]	6689	6690	6690	6690	6690	6689	6689
$Q_{st,aux}$ [kWh/a]	4969	4640	4431	4242	4086	3948	3829
$Q_{st,coll}$ [kWh/a]	2908	3371	3719	4040	4331	4603	4841
$Q_{st,dhw}$ [kWh/a]	3128	3128	3129	3129	3129	3129	3129
$Q_{st,sh}$ [kWh/a]	3561	3561	3561	3561	3561	3560	3561
$W_{pump,sol}$ [kWh/a]	151.77	149.61	146.18	144.25	143.35	142.96	142.13
W_{burn} [kWh/a]	97.49	96.34	95.72	95.05	94.56	94.14	93.83
W_{contr} [kWh/a]	8.76	8.76	8.76	8.76	8.76	8.76	8.76
$W_{pump,SH}$ [kWh/a]	317.45	317.43	317.42	317.43	317.46	317.45	317.44
$W_{pump,DHW}$ [kWh/a]	7.78	7.78	7.78	7.78	7.78	7.78	7.78
W_{total} [kWh/a]	583.26	579.92	575.87	573.27	571.91	571.10	569.94
$Q_{pen,45}$ [kWh/a]	120.02	144.23	83.82	61.65	63.24	58.45	47.20
$Q_{pen,25}$ [kWh/a]	29.81	29.81	29.81	29.81	29.81	29.81	29.81
$Q_{pen,20}$ [kWh/a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$Q_{pen,red}$ [kWh/a]	119.93	144.14	83.73	61.56	63.15	58.36	47.12
FSC	0.516	0.555	0.588	0.622	0.655	0.688	0.721
$f_{sav,therm}$	0.356	0.397	0.423	0.447	0.466	0.483	0.497
$f_{sav,ext}$	0.294	0.331	0.355	0.376	0.393	0.408	0.421
f_{si}	0.282	0.317	0.346	0.370	0.386	0.402	0.416

Table 49: Results of MaxLean system simulations for the Climate Zurich with SFH15 with specific storage volume of 0.07 m^3/m^2

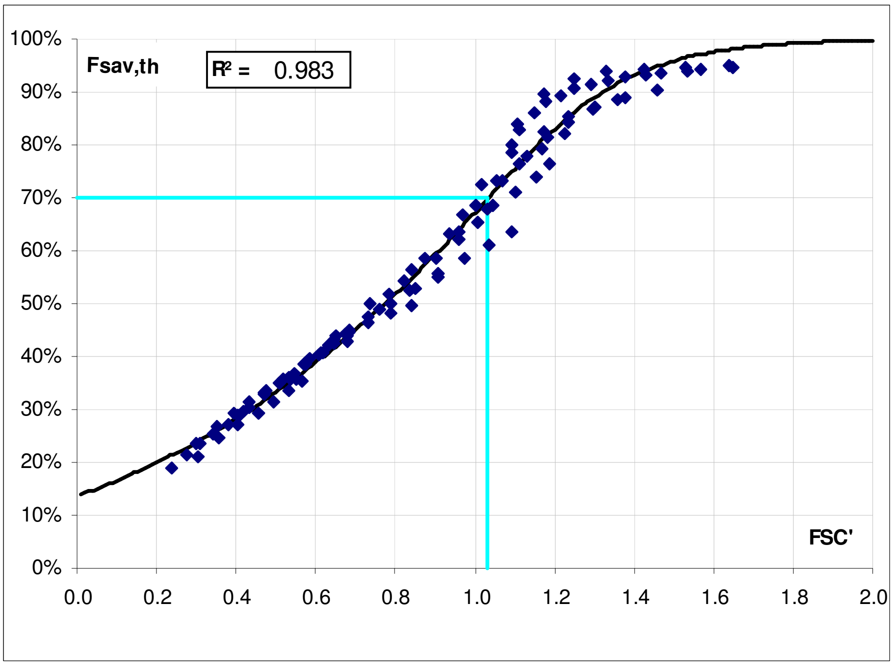

Figure 14: Variation of fractional energy savings with the fractional solar consumption (FSC`) with specific storage volume of 70 l/m^2 for 4 climates (Zurich, Barcelona, Madrid, Stockholm) and 4 buildings

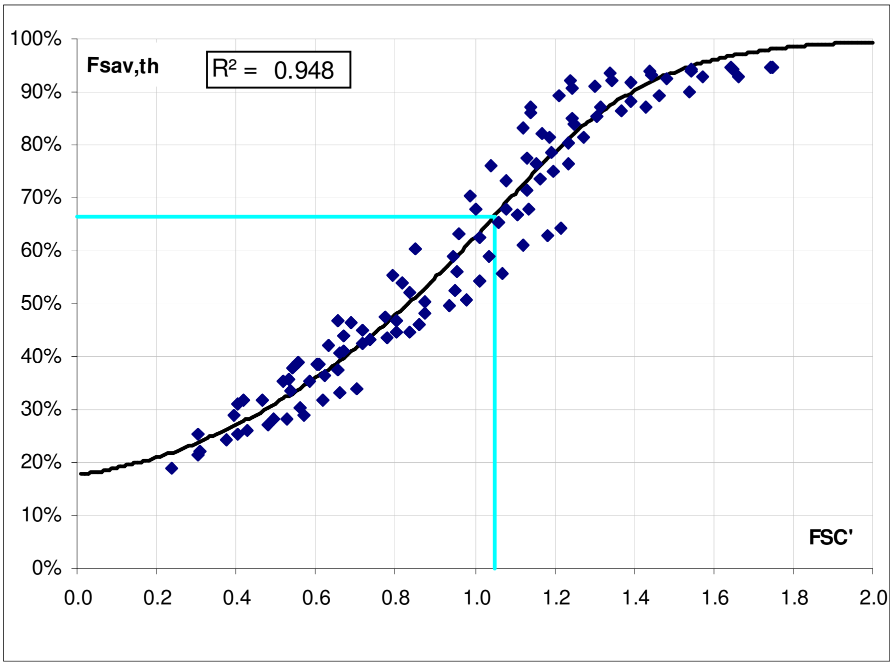

Figure 15: Variation of fractional energy savings with the fractional solar consumption (FSC`) with fixed storage size of 800 litres and different collector areas for 4 climates (Zurich, Barcelona, Madrid, Stockholm) and 4 buildings

9 Appendix 2: Description of components specific to this system

These are components that are
a) not part of the TRNSYS standard library AND
b) not part of the types used as "standard" by Task 26.

9.1 Type 290 : Space heating pump controller

Version 1

Parameters: 7
Inputs: 4
Outputs: 4

Please refer to Direct Feed Flow Controlled Solar Combisystem with Non-pressurized Storage: a Simulation Case; diploma thesis by Martino Poretti [8].

Availability: SPF