solarcombi+

D2.4: Report on specification of component costs

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Identification of most promising markets and promotion of standardised system configurations for the market entry of small scale combined solar heating & cooling applications
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Table of contents

The economic viability of a new technology is a critical factor for its successful market penetration. In the framework of SC+ project and as a part of the market analysis this deliverable aims to analyze the economical parameters related to the commercially available SC+ systems. In specific, the scope of SC+ systems and their current market position are correlated to a cost breakdown and a survey on the relation of technological parameters with capital costs. An economical comparison is then performed between the proposed technology and conventional technologies or technologies that are considered highly competitive. Finally, a learning curve analysis aims to produce an outcome on the prospects of cost reductions.

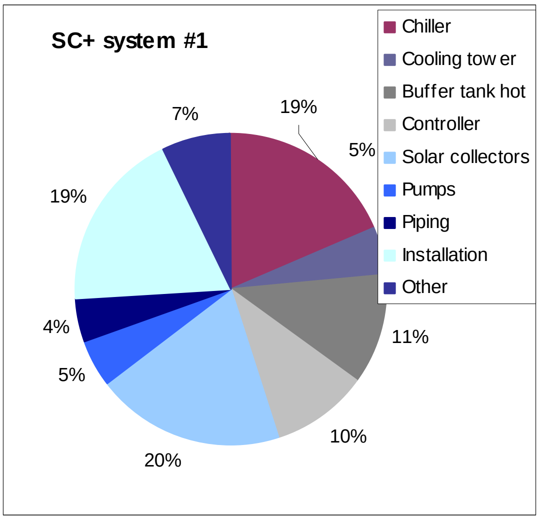
1 Introduction

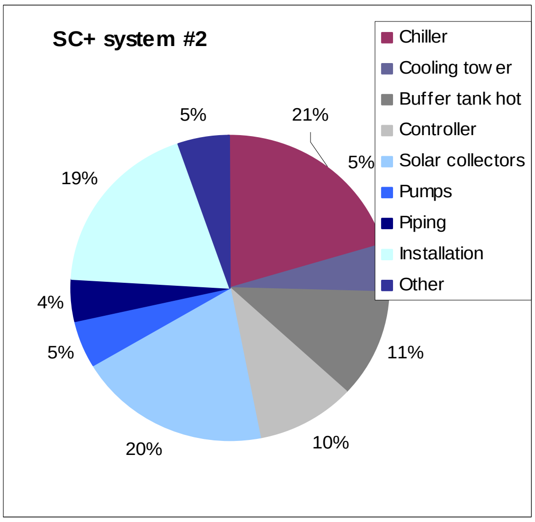
The main purpose of the investigated SC+ systems is the coverage of the cooling load as well as the partial coverage of heating load and DHW. Therefore, their dimensioning is mainly done on the basis of cooling needs. After all, an auxiliary system is most probably also committed to cover the remaining heating load, occurred during times of reduced solar irradiation or increased heating demand. The main component of small scale SC+ systems is the chiller, according to which all other components are being dimensioned.

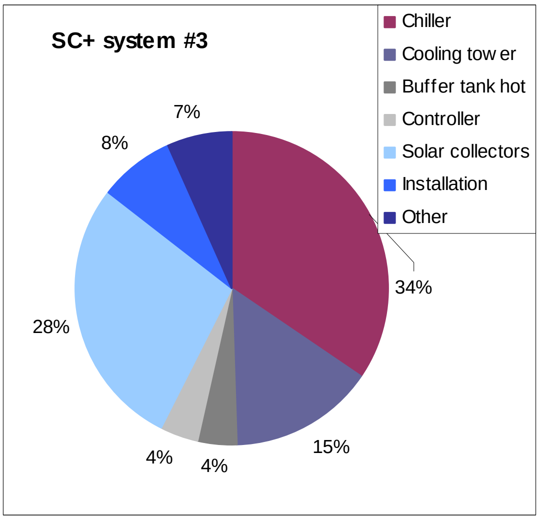
The role of the chiller is accordingly vital for the final cost configurations, normally accounting for the highest share in the total capital cost of the system. Other important component costs include the cost of solar collectors as well as the cooling tower. Besides the capital cost of the system, the final market price depends highly on the retailers' profit margin, as well as transportation and installation costs.

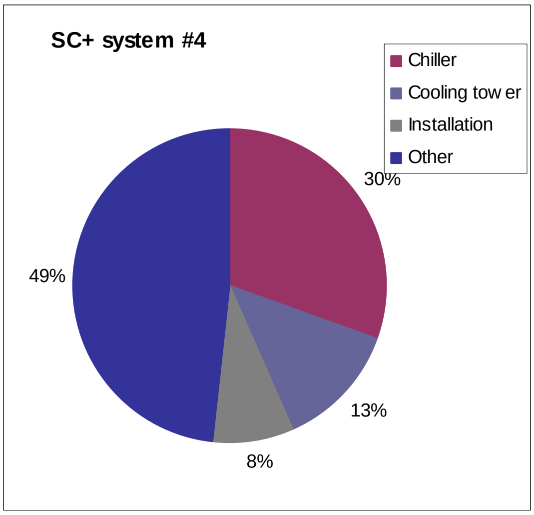
The market analysis performed to collect the required data for the economic evaluation of the SC+ systems was focused on 8 small scale chillers manufactured by the project's industrial partners. To facilitate the collection of data, a questionnaire consisting of acquirements concerning component, maintenance and auxiliary costs, as well as a market assessment was distributed to the industrial partners. The obtained answers included techno-economic data, such as component costs and capacities. However, certain obstacles met made it quite difficult to uniformly collect all the necessary data to conduct a complete economic review. To begin with, most of the industrial partners are just manufacturers of small-scaled chillers and do not offer a complete turn-key solution. For this reason, they are usually unaware of the exact costs for auxiliary components, as they vary among manufacturers. Furthermore, the individual needs of the end user, the intermediate position of the retailer, the installation as well as transportation are cost parameters that vary significantly and cannot be standardized so far. Besides, all the aforementioned factors highlight the fact that the SC+ system cannot be yet characterized as a fully integrated product in the relevant market.

Based on an analysis of the obtained data (provided by the industrial partners) the following figures were obtained to represent the shares of each component cost as well as transportation and installation costs in the final turn-key solution.









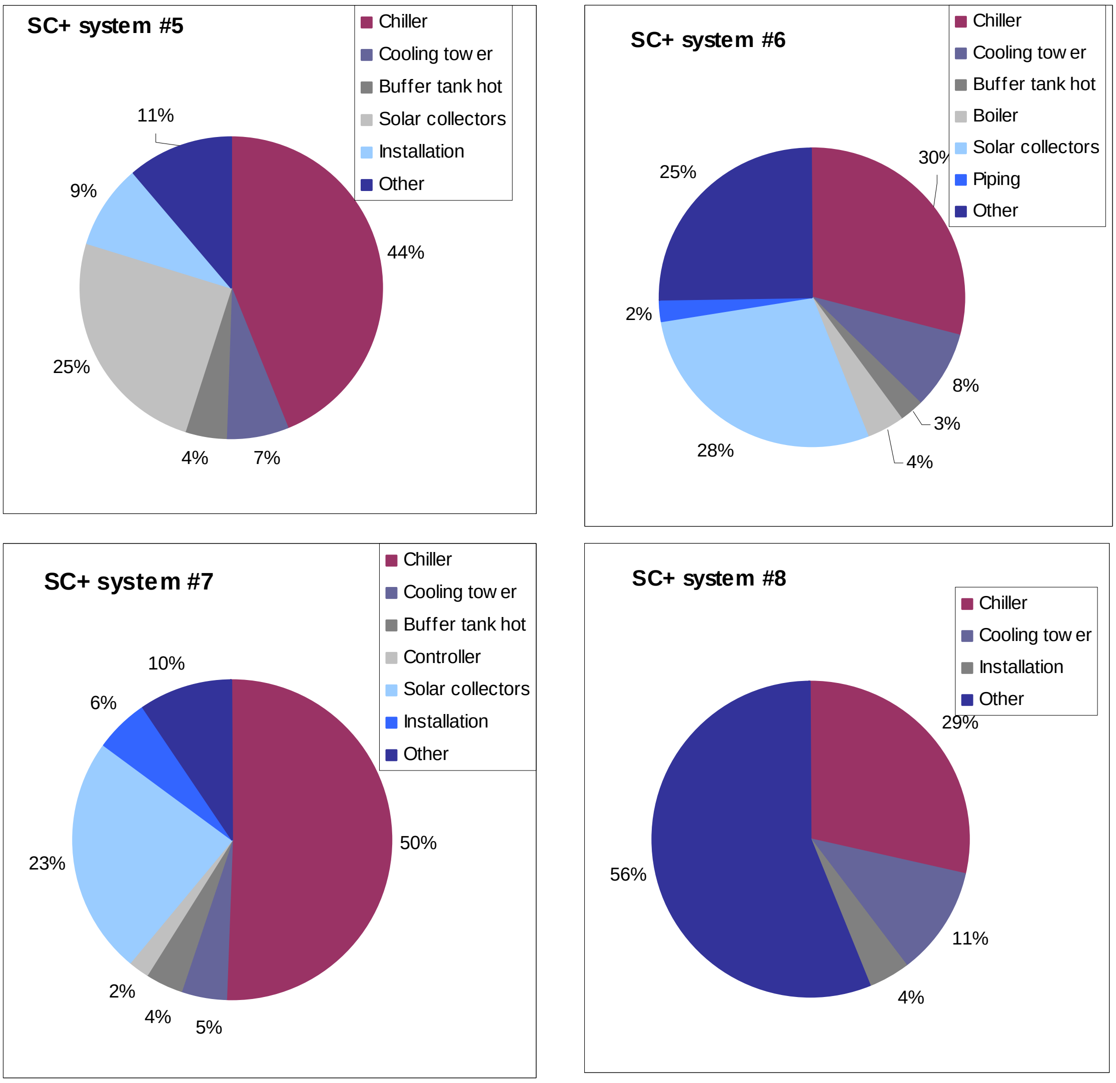


Figure 1: Component cost share of examined SC+ systems

The represented component costs vary in terms of information according to the obtained data; however some general assumptions are made and certain conclusions arise.

The chiller is evidently the most significant component and has the highest cost but also exhibits high deviations as it can vary between 19-50% of the turn-key market price, with an average of 33%. This pronounced variation does not seem to follow any pattern as it is independent of both the chiller capacity and the manufacturer.

The solar collectors, which are being dimensioned around the chiller capacity (3-3.5 m^2 solar panel / kW chiller), hold the second highest position regarding the share of the system's price, i.e. 20 – 34%, with an average of

26%. Finally, the cooling tower accounts for the third most significant cost in the cost breakdown, holding 5-15% of the final market price and an average of 9%.

However, it should be noted that the exact turn-key price is quite uncertain. As established from the graphs of Figure 1, it strongly depends on secondary component costs - as for instance pumps, piping, etc -, transportation and installation, which are seldom offered by the manufacturers themselves and therefore certain assumptions / estimations were made. In some cases, for instance, the installation cost accounts for over 15% of the final market price.

The presented component cost breakdown (significant cost deviations for all components) reveals explicitly the current early stage of the SC+ market in terms of:

- technology development,
- typical systems for specific end user profile,
- performance stability,
- reliability and
- endurance of performance

For instance, the planners or installers of the system have to also consider the risk involved in new technologies for the pricing of their work. When also taking into account that the market price is usually determined by the local retailers, it becomes rather difficult to establish a specific trend regarding the cost breakdown, especially when referring to systems oriented to fulfill single client needs rather than reflecting general market requirements.

In Figure 2 the specific system price (in €/kW) – not including installation and transportation cost - of the examined SC+ systems is represented in descending order. As it is observed in the graph, the allocation of chiller and auxiliary components' cost is quite random. Although it would be expected that the total cost of the SC+ system is weighted by the specific chiller cost, this graph proves that it is mainly defined by the rest of the components that consist the SC+ system.

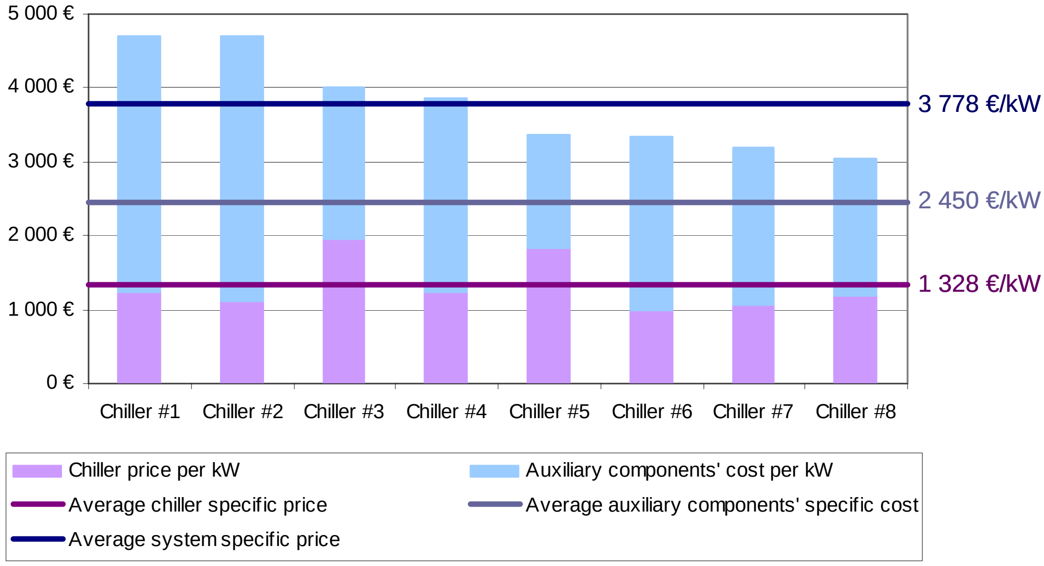


Figure 2: SC+ specific system price

Figure 3 represents the distribution of chillers' price in reference with their capacity.

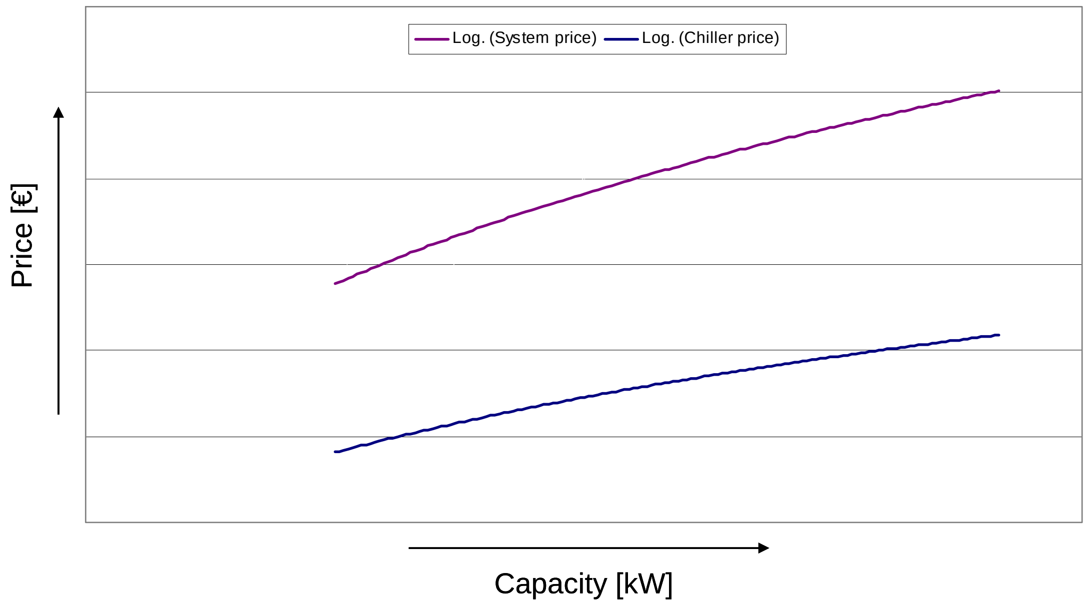


Figure 3: System and chiller price trend

Although there is no confirmation on the accuracy of the systems' turn-key price, the individual system prices of the examined SC+ systems follow a rather expected trend, i.e. increasing with increased chiller capacity. The same trend is observed in the case of the chillers' price alone, which is also anticipated. Following the same methodology, when analyzing the specific system and chiller prices (per $kW_{chiller}$), it would be expected that they either are at least constant or become more economical as the capacity increases, like it has been observed in the cases of other technologies.

However, the graph represented in Figure 4 does not reflect this assumption. On one hand, the system price has a decreasing tendency for larger systems, even though this observation cannot be significantly considered due to the uncertainties regarding turn-key prices mentioned before. On the other hand, the chiller price – which is provided much more confidently by the industrial partners - experiences a slight increase for intermediate capacities. This could be attributed the different manufacturers, specifications and technical characteristics, but, nevertheless, it signifies large deviations in the existing SC+ market.

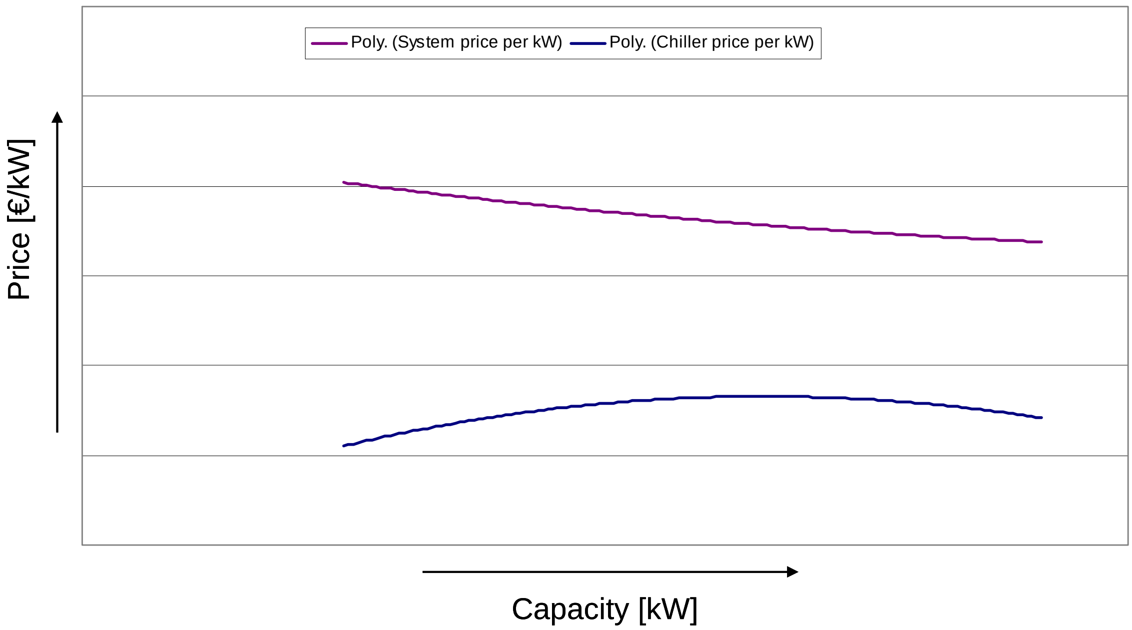


Figure 4: System and chiller specific price

This observation possibly reveals once again that the technology still stands at an emerging market stage, a fact that is mainly detected in the production of custom-made systems, manufactured to implement specific needs, rather than the establishment of an integrated production line to meet varying (cooling & thermal) needs.

Overall, the findings of the conducted analysis around SC+ system and chiller price reveal that the examined market sector is still at a very early market development stage, where no **cost adjustments vs. technological improvements** are yet visible. Moreover, the end-user price is strongly depending (in a non-market competitive way) on the retail chain structure and is influenced not only by technological issues, but also by indirect parameters (i.e. geographical region, profit margin of the retailer, company that provides solar collectors).

A last topic that should be appointed is that, in some cases, there is no trivial trend between chiller specific price and capacity, even when examining chillers with different capacities produced by the same manufacturer. This fact reinforces the previous suggestion regarding the **early market stage of the technology**, as the current small-scaled SC+ market only refers to **tailored systems** and not to systems under an industrial production line.

2 Economic Analysis

As mentioned earlier, an economic viability analysis for new technologies could provide important outcomes as regards the prospects for their development and establishment in the respective markets. Therefore, this section aims to present a complete economic analysis of small-scaled SC+ systems, which is conducted on the basis of two different cases.

- The first case refers to the payback period for the replacement of the existing heating and cooling technologies by a SC+ system in both a given single family house and an office building.
- The second case compares alternative investments – one of which refers to a SC+ system – for the planning of heating and cooling in new buildings (again in the cases of both a single family house and an office building).

More specifically the cases examined are presented in the following table:

Table 1: Examined cases

CASE A: Existing buildings

A.1. Single family house

		Existing system	Existing distribution system	Replacement examined	Required installation of distribution system
A.1.1	Heating Cooling	*Boiler* *Split units*	*Radiators* -	*SC+ (& boiler)*[1]	*Radiant floor*
A.1.2	Heating Cooling	*Boiler* *Split units*	*Radiant floor* -	*SC+ (& boiler)*[1]	-

A.2. Office building

		Existing system	Existing distribution system	Replacement examined	Required installation of distribution system
A.2.1	Heating Cooling	*Heat pump*	*Fancoil units*	*SC+ (& heat pump)*[2]	-

[1] The installation of a boiler as the auxiliary heating system is not required in this case, since it already exists in the building

[2] The installation of a heat pump as the auxiliary heating system is not required in this case, since it already exists in the building

CASE B: New buildings

B.1. Single family house

		System #1	Distribution system #1	System #2	Distribution system #2
B.1.1	Heating	*Boiler*	*Radiant floor*	*SC+ & boiler*	*Radiant floor*[3]
	Cooling	*Split units*	-		
B.1.2	Heating Cooling	*Heat pump*	*Radiant floor*	*SC+ & boiler*	*Radiant floor*[3]
B.1.3	Heating Cooling	*Geothermal Heat Pump*	*Radiant floor*	*SC+ & boiler*	*Radiant floor*[3]

B.2. Office building

		System #1	Distribution system #1	System #2	Distribution system #2
B.2.1	Heating Cooling	*Heat pump*	*Fancoil units*	*SC+ & boiler*	*Fancoil units*[4]

The choice of alternatives to SC+ systems (i.e. boiler, split units, heat pump and geothermal heat pump) was made according to competition which is detected not only to new and efficient technologies, but also to the most conventional ones. In specific, when the industrial partners were asked to state and rate the most competitive systems for heating and cooling Figure 5 came along.

[3] The installation of radiant floor will not be considered in the economic analysis as it can be eliminated from both alternatives

[4] The installation of fancoil units will not be considered in the economic analysis as it can be eliminated from both alternatives

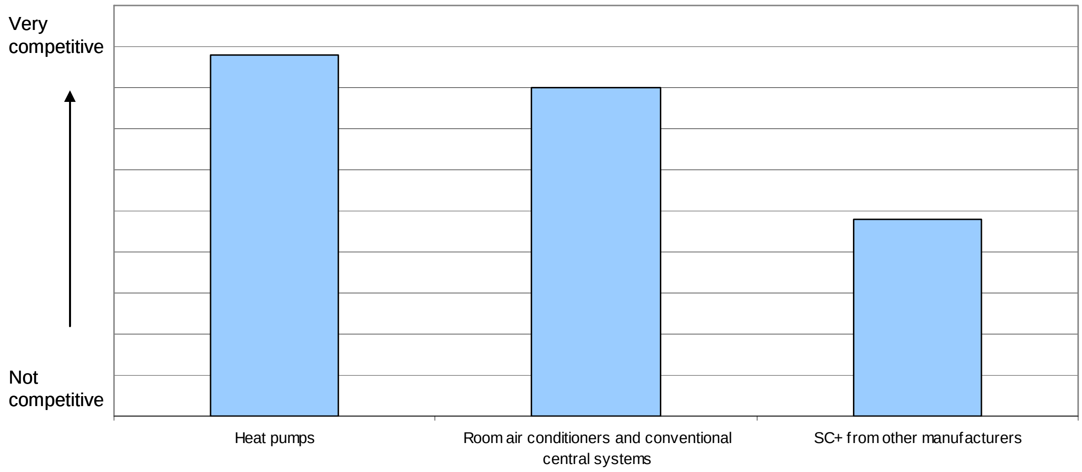


Figure 5: Most competitive systems for heating and cooling towards SC+ systems

As it is observed, heat pumps are considered the most competitive technology in terms of techno-economical characteristics, whereas conventional room air conditioners and central systems still sustain a competitive position. Therefore, in the consideration of alternatives for new buildings, heat pumps as well as boilers and split units are chosen to compete with SC+ systems.

In order to conduct a reliable economic comparison of the alternative investments, it was attempted to collect as realistic data as possible. The data refer to technical, economic and climatic characteristics. The region chosen for the implementation of the analysis is Toulouse, with climatic data (irradiation), obtained by Fraunhofer ISE. The heating and cooling loads for the investigated buildings (both single-family house and office) were also obtained by Fraunhofer ISE and, then, corrected to reflect cooling needs that can be fully covered by the considered small-scaled SC+ chiller.

As mentioned in paragraph 1, there has been an uncertainty concerning the final cost of the SC+ system, evaluated from the partners' answers. Since there is no reliable source for the final cost, it is assumed to be the average of the final costs as provided or presumed by the industrial partners. The assumptions made around the small-scaled SC+ system that participates in the analysis are given in Table 2.

Table 2: Assumptions on techno-economical characteristics for SC+ systems

Final capital cost	*35 562 €*
Chiller capacity	*10 kW*
Solar collectors surface	$3\ m^2/kW_{chiller}$
Solar collectors efficiency	*56%*
Chiller efficiency	*60%*

Solar circuit losses	*20%*
Electricity consumption for pumps' operation	*900 kWh/y*

Correspondingly, Table 3 represents the parameters that are relevant to the selected buildings as well as the techno-economic characteristics of the alternative investments considered.

Table 3: Assumptions on techno-economical characteristics for alternative investments

	Single-family house	Office building
Heating load	*24 702.10 kWh/y*	*4 716.06 kWh/y*
Cooling load	*3 054.02 kWh/y*	*6 949.85 kWh/y*
Heating peak capacity	*18 kW*	*8 kW*
Cooling peak capacity	*10 kW*	*10 kW*

	Capacity	Efficiency/ COP	Cost	Capacity	Efficiency/ COP	Cost
Gas boiler	*24 kW*	*0.85*	*900 €*	*24 kW*	*0.85*	*900 €*
Split units (x5)	-	*2.5*	*4 500 €*	-	-	-
Heat pump	*17 kW (c)* *18.5 kW (h)*	*3.0* *3.5*	*7 000 €*	*13 kW (c)* *16 kW (h)*	*3.0* *3.5*	*4000 €*
Geothermal heat pump	*18.6 kW (c)* *22.7 kW (h)*	*4.0* *4.9*	*26 150 €*	-	-	-
Installation of radiant floor	*140 m^2*	-	*7 000 €*	-	-	-

The SC+ system is assumed to fully cover the cooling loads during most of the period considered. This assumption is fairly reliable, since the SC+ system is assumed to have been dimensioned adequately to cover the cooling needs and moreover the cooling period normally coincides with the maximum irradiation period. On the other hand, a slight deviation of the ability to cover some peak cooling loads can be neglected, since the purpose of the system is focused on the coverage of the average cooling load.

On the other hand, the heating load can be only partially covered by the SC+ system and has to be accompanied by an auxiliary system. The average heating demand coverage by the SC+ system was calculated equal to 52.59% for the single-family house and 74.57% for the office building. The calculations were based on the potential heating output of the SC+ system (taking into account the aforementioned irradiation and efficiencies) and compared to the daily heating load.

$$H = IR \cdot A \cdot \varepsilon_{sol} \cdot (1 - L) \qquad (2)$$

Where H : heating output [Wh/$kW_{chiller}$/y]
IR : irradiation [Wh/m^2/y]
A : solar collectors' surface [A]
ε_{sol} : solar collectors' efficiency [%]
L : solar circuit losses [%]

Both the boiler and the heat pump are being dimensioned to cover the peak load even if they are only implemented as an auxiliary heating system for the SC+ system. This assumption is more than reasonable, since the auxiliary heating system aims to cover the heating load at most extreme circumstances, i.e. with no irradiation and high heating demand.

Finally, it is assumed that the current gas price in France for domestic users accounts for 0.09 €/kWh$_{th}$ and the electricity price 0.14 €/kWh[5].

It should be noted, that the maintenance costs are not considered in the economic analysis in any case examined. Both the uncertainty around the exact amount of maintenance costs for all the components of the systems, as well as the assumption that the maintenance costs do not significantly differentiate the final conclusions, allow their disregarding in the analysis that follows.

2.1 Case A: Existing buildings

The method implemented for the economic evaluation of the existing systems' replacement by SC+ systems is the assessment of the payback period. The payback period is determined by considering the total energy savings that occur yearly and then subtracting them from the initial investment. In specific, the formula used to determine the payback period is as follows:

$$PB = \frac{\ln\left[1 - \frac{CC}{E}(r-i)\right]}{\ln\left[\frac{1+i}{1+r}\right]} \qquad (2)$$

Where PB: payback period [y]

CC: capital investment [€]

E: energy savings [€/y]

r: market discount rate (assumed 3%)

i: energy inflation (assumed 4%)

In case A.1.1 (see Table 1), the investment considered refers to the installation of a SC+ system to replace five split units (see Table 3) and partially the boiler's operation (52.59%). At the same time, radiant floor has to be installed, since the existing radiators are not compatible for cooling. On the other hand, radiant floor has already been committed in case A.1.2 and is not taken into account as an extra cost. Respectively in case A.2.1, fancoil units are already available and, therefore, not considered in the analysis. The total energy consumption of each system refers to their operating costs, i.e. fuel costs to cover the annual heating and cooling

[5] As a general comment, the price of fuel and electricity in France stand in the EU average. Furthermore, the selection of the site was also made in order to present a place with noteworthy thermal & cooling needs, in order to reach more general conclusions when examining the competition.

demand. In addition to the simple case, two further approaches are also considered, i.e. the availability of subsidies (20% and 40% respectively). The results obtained are presented in Table 4.

Table 4: Payback period for the replacement of heating and cooling systems by a SC+ system

A.1. Single family house

	Payback Period [y]	Payback Period with 20% subsidy [y]	Payback Period with 40% subsidy [y]
A.1.1	*27.13*	*22.24*	*17.11*
A.1.2	*23.13*	*18.90*	*14.48*

A.2. Office building

	Payback Period [y]	Payback Period with 20% subsidy [y]	Payback Period with 40% subsidy [y]
A.2.1	*72.17*	*61.22*	*48.97*

Considering that the mean lifetime of a SC+ system is approximately 20 years, it is established that the replacement of existing cooling and heating systems by a SC+ system in a single house would not lead to a reasonable payback time unless a subsidy is foreseen and mostly for case A.1.2, which does not require installing a new distribution system as well. Even longer is the payback time for the office building, where the replacement of a heat pump is examined, which makes this potential exorbitant.

2.2 Case B: New buildings

For the economic comparison of different investment plans for heating and cooling of new buildings the method of the net present value (NPV) is being implemented. In specific, the net present value is calculated for the time period of the systems' lifetime, which is assumed to be 20 years. The NPV is given by the following formula.

$$NPV = OC\left[\frac{1-\left(\frac{1+i}{1+r}\right)^{n}}{r-i}\right]+CC \qquad (3)$$

Where NPV : net present value [€]
OC : operating costs [€]
i : energy inflation (4%)
r : market discount rate (3%)

n: lifetime (20 years)
CC: capital cost [€]

In all cases, the alternative investment is the SC+ system selected (with a boiler also committed to fill the remaining heating load of approximately 11 712 kWh/y) and it is opposed to the conventional boiler and split units as well as the most competitive heat pump and geothermal heat pump. The calculated net present values for each investment are presented in Table 5.

Table 5: NPV of alternative investment plans for new buildings

Cases	Single family house B.1.1	B.1.2	B.1.3	Office building B.2.1
NPV for competing system [€]	*64 801*	*31 101*	*41 195*	*14 935*
NPV for SC+ system [€]	*65 584*	*65 584*	*65 584*	*41 856*
NPV for SC+ system with 20 % subsidy [€]	*58 291*	*58 291*	*58 291*	*34 563*
NPV for SC+ system with 40% subsidy[€]	*50 999*	*50 999*	*50 999*	*27 271*

As in Case A, the purchase and installation of a small-scaled SC+ system (together with a boiler for the coverage of the remaining heating load) does not seem cost-effective in most comparisons.

However, in case B.1.1 it is proven that even a rather low subsidy for committing a SC+ system is more beneficial than installing the conventional boiler and split units. It is essential, though, to mention the fact that the actual cost affecting the NPV of each investment plan is detected in the operating cost and not the capital cost. The NPV is considered for a time period of 20 years, what makes the value of the capital investment minor compared to the costs spent for operating the systems. Therefore, another scenario was examined, where the SC+ system to be committed is accompanied by a heat pump (as the auxiliary heating system). The NPV for this alternative accounts for 55 235 € for the single family house, which is fairly lower than the alternative with the boiler as auxiliary heating system. On the other hand, when considering the office building, the NPV of the SC+ system with HP becomes higher (46 460 €) than the one with boiler. This is merely explained by the level of heating demand in the office building. The fact that it is rather low (see Table 3) makes the installation of the expensive heat pump non-profitable even for the long period of 20 years.

3 Potential for cost reductions of SC+ systems

A survey conducted among the industrial partners of the SC+ project included their opinion on the most efficient ways of boosting the small-scaled SC+ systems' penetration into the relevant market. According to their replies, cost reduction was rated as the number 1 parameter for a more intensive market penetration (see Figure 6), what has been also determined in the previous paragraph. Therefore, in this section an analysis on the prospects for cost reduction will be performed.

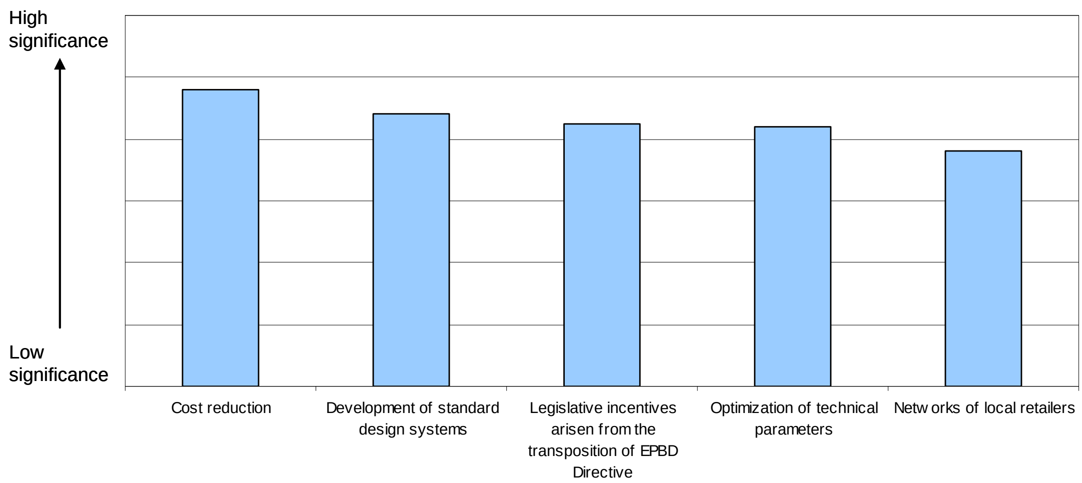


Figure 6: Rated parameters for further market penetration of small-scaled SC+ systems

There are a number of different methodologies for evaluating the cost (and price) reductions for new technologies, including, of course, a detailed techno-economical assessment, carried out through the correlation of the manufacturing cost breakdown and possible improvement of technological parameters. However, a rather popular approach of assessing future cost reductions has been proven to be the learning curve methodology. The basic idea refers to the theory of learning by doing, i.e. repetition of the same operation results in less time or effort expended on that operation.

It is common, that investments in new technologies are more expensive than those in old technologies. However, new technologies can be assumed to become more economical as their market share increases, so that eventually they are more attractive than the respective old technologies, which have already reached maturity and have no further potential for cost reductions. A typical learning curve for energy technologies is represented in Figure 7

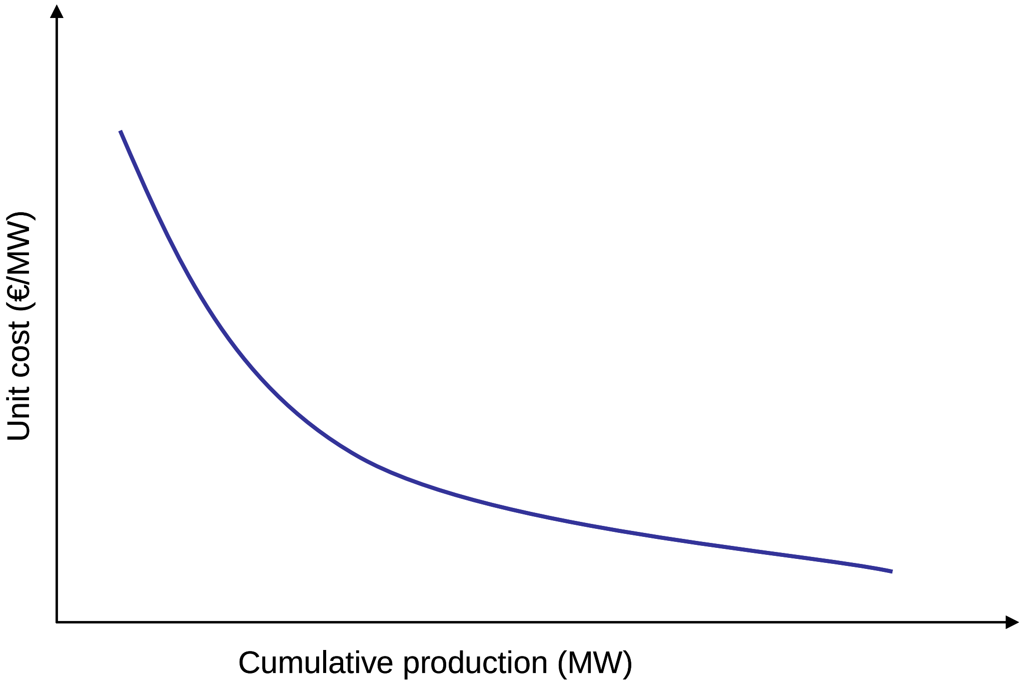


Figure 7: Learning curve

The experience gained by manufacturing a certain technology (it may refer to cumulative production or market share) is expressed as learning rate. Typically, the learning rate can be expressed as the rate at which the unit cost of a technology decreases every time the cumulative production is doubled and it is reflected by the slope of the learning curve when plotted in logarithmic scale. The learning rate is normally not stable throughout the lifetime of a technology (from invention to senescence). It has been observed, though, that mean learning rates for energy technologies usually range from 10 to 30%, while 20% is considered to be a good estimation for future cost reduction potential (2).

Learning rates are based on historic data concerning technologies that followed a typical progress, i.e. emergence, commercialization and maturity. However, there is no guarantee that a given technology will have such an evolution, as it depends on various parameters, for instance losing out to competing technologies.

The learning curve methodology can be employed as a tool for assessing the cost reduction potential of a small-scaled SC+ system, by determining the break-even point. This is defined as the level of market deployment (expressed in cumulative systems sold/installed) required for the small-scaled SC+ system's production (which is reflected through the capital cost) to become competitive with a conventional system, i.e. having comparable capital cost (which also reflects the production cost) with the conventional (or competing) technology. The number of SC+ cumulative installations for reaching the break-even point is calculated by the following equation:

$$n_b = n_0 \left(\frac{c_b}{c_0} \right)^{1/a} \qquad (4)$$

Where n_b: SC+ cumulative installations at break-even point

n_0: current cumulative installations of SC+ systems

C_b: cost/price of reaching break-even point

C_0: current capital cost/price of SC+ system

a: learning elasticity parameter, which is defined as:

$$a = \frac{\log(1-r)}{\log 2} \qquad (5)$$

and r: learning rate

Assuming that the specific cost of a conventional technology (boiler and split units) is 540 €, the one of a highly competitive technology (heat pump) 700 € and the one of the SC+ system 3 556 €, Table 6 presents the results obtained as function of the learning rate.

Table 6: Required market development to reach break-even point

Learning rate	30%	25%	20%	15%	10%
n_b/n_0 to reach break even with conventional technology	*39*	*94*	*349*	*3 100*	*242 866*
n_b/n_0 to reach break even with highly competitive technology	*24*	*50*	*156*	*1 025*	*44 046*

As represented in Table 6, a high learning rate denotes a rather moderate increase necessary to achieve the presumable competitive price. Specifically, with a learning rate of 30%, the number of SC+ systems' installation has to become 39 times larger than the current number to compete the conventional technology and 24 times larger to compete the highly competitive technology. On the other hand, a significantly lower learning rate of 10% suggests that the number of installations has to increase 242 866 times to compete the conventional technology and 44 046 times to compete the heat pump. However, it should be mentioned that these figures are statistical based estimations and should not be treated as strict targets in order to achieve high market penetration for the SC+ systems.

Furthermore, the obtained results are in a somehow accordance with the provided feedback by the industrial partners (presented at D2.1, figure 17), who already bear in mind that in order to achieve the first fraction of the required price reduction (accompanied by a respective reduction of the manufacturing cost) a significant increase at the volume of sales is needed.

In any case, this analysis denotes that the SC+ systems have to *transit from their currently early market stage to the next market levels* in order to become competitive with the conventional technologies. Even if a rather optimistic learning rate of 30% is assumed, the production numbers have to significantly increase in order to achieve the cost-competitiveness of a conventional system. Accordingly, **mass production of SC+ systems leads to economies of scale** that further reduce the long-run average costs of production.

For this production increase to take place, it is essential to recognize **standard system configurations** in order to facilitate the production line and proceed to **design package solution**, for the technology to successfully evolve in the relevant market.

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