Solar Hot Water Systems in the buildings of kindergartens in the municipality of Blagoevgrad

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Updated 30.05.2022

International Development Norway

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Introduction

With the increasing emphasis on using clean alternative fuel sources and reducing carbon emissions, deploying solar thermal systems has been given unique attention. Several types of solar thermal systems are available, such as flat-Plate collectors, evacuated-tube collectors, parabolic trough, parabolic dish, power tower, solar collectors, or solar cells. In terms of efficiency, evacuated-tube collectors are the most efficient while they are the most expensive.

This report aims at presenting the design layout of solar thermal systems for ten case studies in Bulgaria as part of the project of implementation of measures for successful adaptation to climate Change Grant Agreement (GFPA) № D-33-52 / 08.11.2021 (UMIS number: BGENVIRONMENT-4.003-0017-C01) under the Environmental Protection and Climate Change Program, funded by The Financial Mechanism of the European Economic Area 2014-2021. In the project, several requirements have been proposed.

The first section of this report presents these requirements and introduces all the case studies. Moreover, the modeling and essential simplifications have been discussed.

Next, the results are presented and discussed. All cases are modeled separately and individually. Based on the potential in each case study, more than one installation scenario has been given.

Goals and requirements

This project's primary goal is to document for implementation, deliver, install, and put into operation the solar systems for domestic hot water supply (DHW) through solar / vacuum-tube / collectors, 10 (ten) buildings of kindergartens in the municipality of Blagoevgrad.

All the case studies are shown in Table 1, naming them from cases 1 to 10. As can be seen, there are two main differences: The number of total people (Children and staff), which influences the hot water consumption, and the available roof area. However, the functional area may be much less than the available area. This is displayed in the next part.

Table 1. Total number of hot water users and the available roof area

Case number	Name of kindergarten	Number of children	Staff	Total	Roof area
Case 1	No 1 "Ведрица"	159	29	188	265
Case 2	No 3 "Детелини"	168	30	198	400
Case 3	No 4 "Роса"	158	28	186	350
Case 4	No 6 "Щастливо детство"	170	27	197	1200
Case 5	No 8 "Вечерница"	111	20	131	350
Case 6	No 12 "Алени макове"	115	25	130	285
Case 7	"Детски свят"	216	33	249	330
Case 8	"Синчец" - филиал, с. Зелен дол	10	3	13	-
Case 9	"Усмивка", Филиал - с. Покровник	18	3	21	325
Case 10	"Усмивка", Филиал - Ц. Церово	15	5	20	408

The current hot water production systems use electric boilers and gas boilers. The detailed capacity is shown in Table 2. The water consumption data includes both cold and hot water use. The initial cold-water temperature can vary throughout the year, but the hot water temperature is constant at 55℃. An experimental number for water use for normal buildings shows that hot water is regarded as 30% of total water consumption (1). This fraction is being considered for the daily hot water consumption for the kindergartens.

Table 2. Hot water production and capacity in case studies

Case number	The current capacity of hot water storage (L)	Daily consumption of water (m3)	The current source of water heating
Case 1	560 (80 L each)	4.4	7 Electric boilers
Case 2	500	6.1	Five electric boilers, 1 Gas boiler
Case 3	700 (80 L each electric and 300 L for the gas boiler)	4.0	Five electric boilers, 1 Gas boiler
Case 4	860	8.1	Electric boilers

Case 5	780 (80 L each electric and 300 L for the gas boiler)	4.1	6 Electric boilers 1 Gas boiler
Case 6	760 (80 L each electric and 200 L one of the electric boilers)	5.4	8 Electric boilers
Case 7	800 (80 L each electric and 2000 L for the gas boiler)	7.5	Ten electric boilers, One gas boiler
Case 8	86 (1 electric boiler with 80 L and 3 small electric boilers)	0.1	1 electric boiler
Case 9	80	0.4	1 electric boiler
Case 10	100 (50 L each)	1.0	2 electric boilers

For the system design, constraints are considered based on the project description. These constraints are:

1. The collectors should be installed on the roof of the designated buildings, in one row, at a slope of 45°(for year-round operation).
2. The orientation of the panels should be to the south.
3. The collector part should be with a propylene glycol heat carrier or other liquid suitable for year-round DHW installations.
4. Absorption coefficient (α)≥ 90%
5. Emission factor (ε) ≤ 6%
6. Summary heat loss coefficient (UL< 1.5 W / m^2K)
7. The system must provide the entire amount of hot water for each site throughout the year (capacity in liters of water with a temperature of 55 ° C per day according to the data in the attached table for the site).
8. The share of energy from the sun should be not less than 55%.

Solar collector modeling

Data from Geographical Information System (PVGIS) (2), and System Advisor Model (SAM) software (3) is used to model the potential of hot water production generation.

The Solar Water Heating model represents solar collectors with a one-tank water or glycol storage system and an auxiliary electric heater as one of the SAM modules. SAM models a closed-loop collector that transfers solar energy from the working fluid to the water in an external heat exchanger. This setup is often used in climates where freezing temperatures occur because the collector working fluid can be different than water. Water from the solar tank is typically used to preheat the water in an auxiliary tank and reduce the amount of heat needed to bring the delivered water to the set point desired by the user. In the model used here, the solar tank is filled with water from the mains, pumped through the heat exchanger, and returned to the top of the tank.

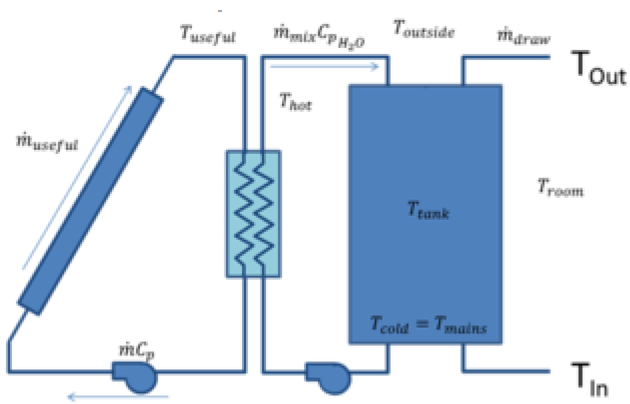

Figure 1.Schematic of solar water heating model

Hot water production capacity

In order to evaluate the hot water production capacity by the solar collectors, similar approaches have been used in all the cases.

1. One type of solar heating collector is used.
2. The available and potential areas are being shown, and the installment section is presented.
3. The hot water production capacity and the auxiliary power needed for supplying all the hot water are shown daily.
4. All the requirements (constraints) from the previous section are considered.
5. If feasible, more than one scenario is given.

Specifications of solar heating collector

As one of the requirements in the project proposal, HTP Evacuated Tube Heat Pipe Solar Collectors, HP-30SC, is chosen. Other specifications are presented in Table 3:

Table 3. Solar heating collector specification

Model	HP-30SC
Dimensions	2.56 m * 2 m
Nominal flow rate	0.053 kg/s
Proposed storage tank size	+265 liter
Number of tubes	30

System performance is a function of two variables. The hot water production varies during a day in different months of the year according to the availability of the sun and its irradiation factors. The second variable is the consumption rate and profile. It can be assumed that the hot water consumes only during the day's working hours in the kindergartens. This item is very significant in the sizing of the auxiliary boiler since the collectors provide no hot water at night. Therefore, normalized hot water consumption is applied and can be seen in Figure 2. This normalizing factor applied for the entire working day. For example, case one with 1320 liter consumption a day is converted to Figure 3 with a maximum flow rate of 120 L/h.

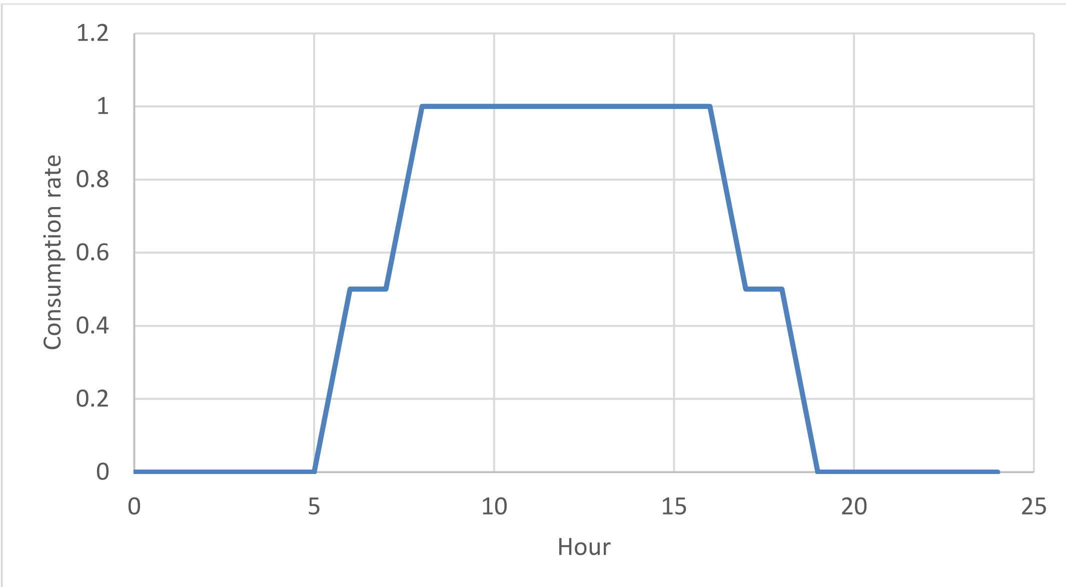

Figure 2. Hot water consumption rate during a day

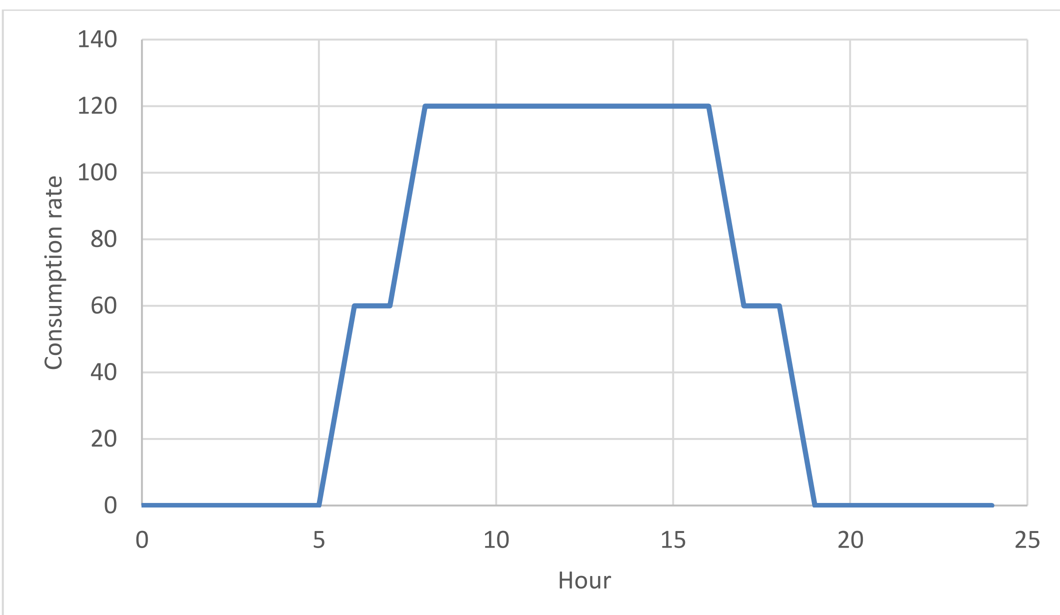

Figure 3. Hot water consumption during a day for case 1

In the modeling, the shading factor is given zero. This assumption is correct if just one row of solar collectors is installed, and no building or tree is close to the roof.

Case 1: Ведрица (Vedrica)

This kindergarten has a sloping roof with a total area of 265 m^2.The water consumption is 4.4 m^3 per day.This gives a hot water consumption of 1320 liters.

Figure 4.The building's front view

This building's roof is south/north.Thus, half of the roof is suitable for installing the collector.This area is shown in Figure 5.As can be seen, the solar collector has the available space to be installed in one row of a maximum of about 14 meters. The width of the collector is 2.5 m. There are some ups and downs on the roof, which are not apparent in the picture. Considering a tilt installation of the collector, these bumpers can be skipped.

Figure 5.The building's top view

The first scenario provides at least 55% of the hot water production. This means the solar collector must provide 726 liters of hot water at 55° C per day.

Installing four collectors gives the following output in a year:

Table 4. Annual energy saved with four solar collectors

Annual energy saved (year 1)	14,194 kWh
Solar fraction (year 1)	0.56
Aux with solar (year 1)	11,127.2 kWh
Aux without solar (year 1)	25,519.7 kWh

The total energy needed for the hot water of this kindergarten is 25,5 MWh. Solar collectors can provide 14,1MWh during the year, 56% of the total energy. The rest of the energy, which is about 11 MWh, should be supplied by the auxiliary boiler.

As an example, the energy required in June, produced by the solar collector and provided by the auxiliary boiler, is shown in Figure 5. In addition, the rest of the monthly energy production by four solar collectors is shown in Figure 7.

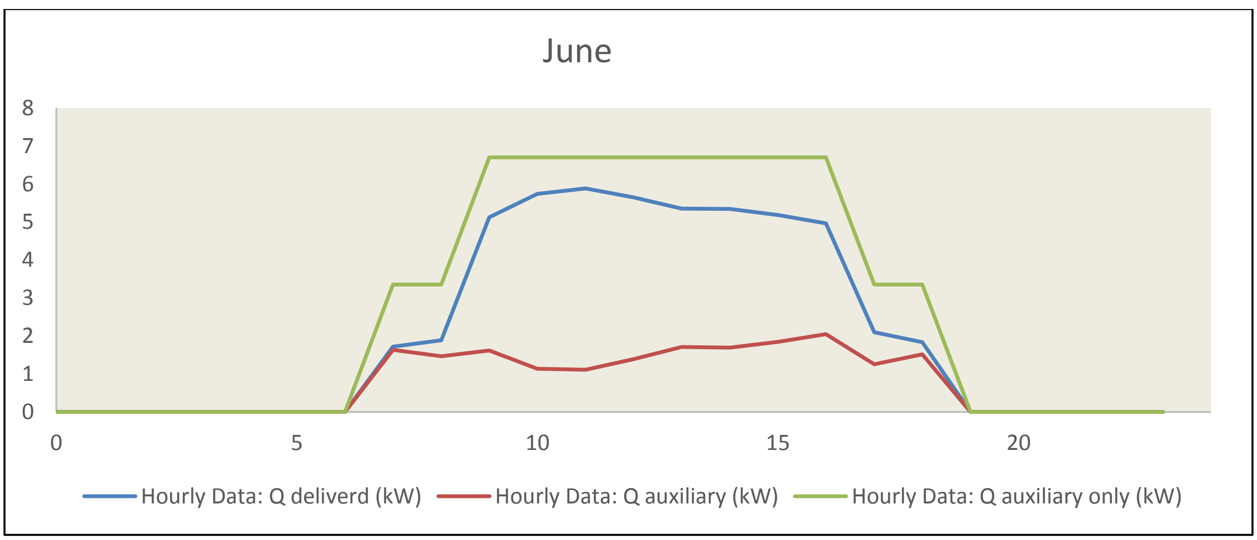

Figure 6. Daily power needed for hot water production, provided by the solar collector, and the need for other auxiliary boilers in case 1

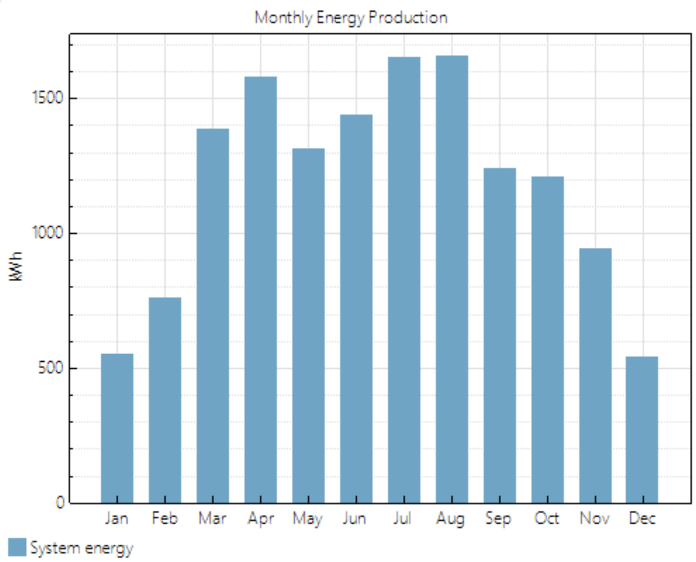

Figure 7. Monthly energy production by four solar collectors in case 1

The second scenario shows the maximum capacity of hot water production by the solar collectors by considering the one-row installation in the south direction. This means the solar collector must be installed in a row with a 14-meter length for this case, which gives seven collectors. With this number and area of the collectors, 73% of the total hot water can be provided by solar collectors, and the electric boilers should supply 27%.

Table 5. Maximum possible annual energy saving with solar collector

Annual energy saved (year 1)	18,687 kWh
Solar fraction (year 1)	0.73
Aux with solar (year 1)	6,642.2 kWh
Aux without solar (year 1)	25,519.7 kWh

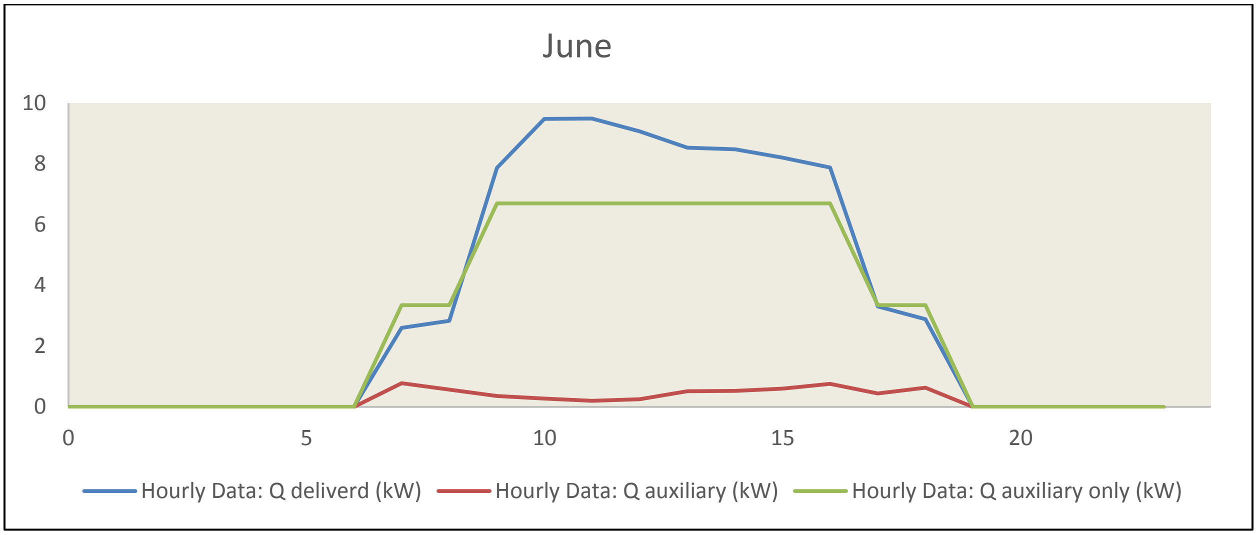

Figure 8. Maximum capacity of hot water production, provided by the solar collector, and the need for other auxiliary boilers in case 1

Case 2: Детелини (Detelini)

This kindergarten has a flat roof with a total area of 400 m^2. The water consumption is 6.1 m^3 per day. This gives a hot water consumption of 1830 liters.

Figure 9. The top view and possible installation length of case 2

To provide at least 55% of the hot water production for the first scenario, the solar collector must provide 1006 liters of hot water at 55° C per day. This means six collectors or 12,7m2 of collector surface.

Table 6. Annual energy saving with six solar collectors in case 2

Annual energy saved (year 1)	20,266 kWh
Solar fraction (year 1)	0.57
Aux with solar (year 1)	14,908.2 kWh
Aux without solar (year 1)	35,379.6 kWh

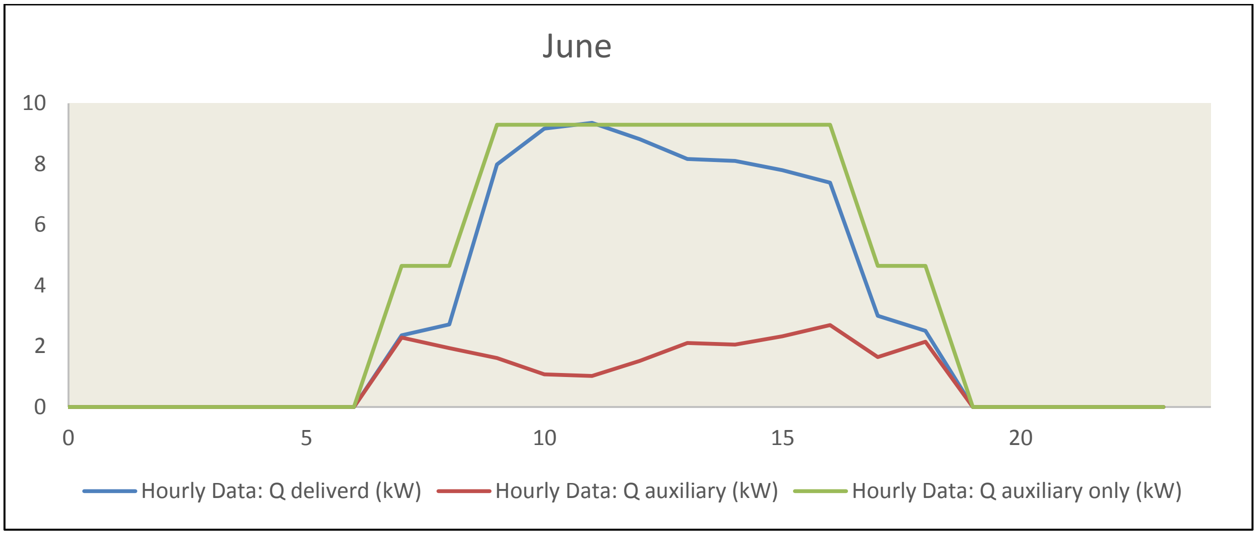

Figure 10. Daily power needed for hot water production, provided by the six solar collectors, and the need for other auxiliary boilers in case 2

However, with 10 meters of length available on top of the roof in the south direction, it is possible to install only five collectors. Thus, it is recommended to install the collectors angled to provide more area for the collector. Otherwise, the solar collector can give almost 52% of hot water, and the rest half of the energy should be supplied by the electric boilers and gas boilers.

Case 3: Poca (Rosa)

This kindergarten has a flat roof with a total area of 350 m^2. The water consumption is 4.0 m^3 per day. This gives a hot water consumption of 1200 liters.

Figure 11. The front view of case 3

Figure 12. The top view and possible installation length of case 2

In order to provide 660 liters of hot water at 55° C per day, which is 55% of total hot water consumption, four solar collectors are needed.

Table 7. Annual energy saving with four solar collectors in case 3

Annual energy saved (year 1)	13,455 kWh
Solar fraction (year 1)	0.58
Aux with solar (year 1)	9,549.3 kWh
Aux without solar (year 1)	23,199.7 kWh

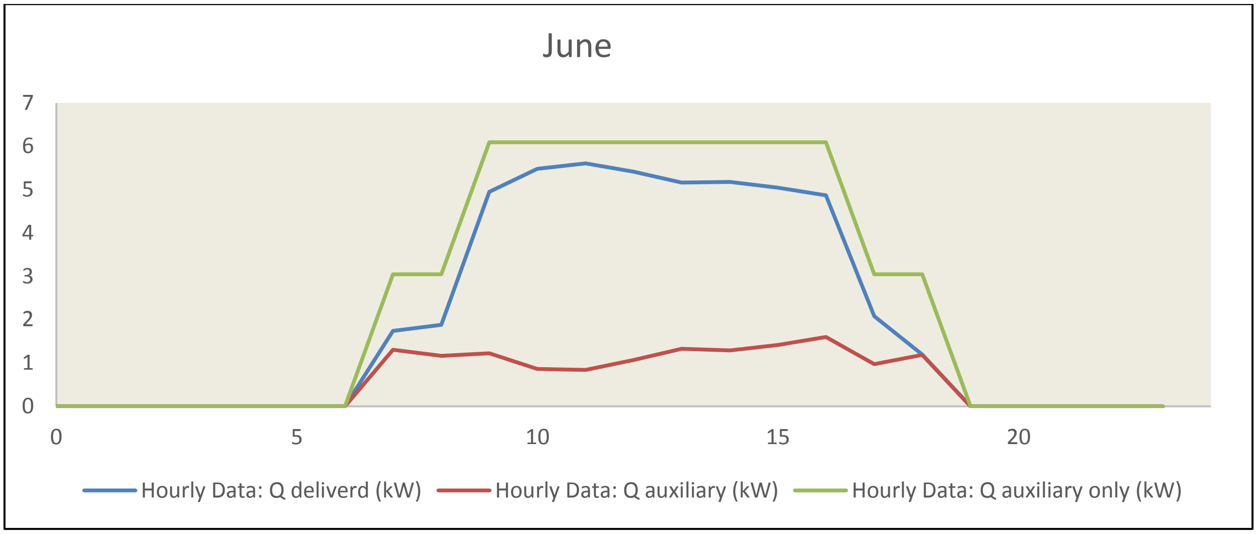

Figure 13. Daily power needed for hot water production, provided by the six solar collectors, and the need for other auxiliary boilers in case 3

In the second scenario, in a length of 20 meters and with ten collectors, the hot water system can reach its maximum production capacity with solar collectors. A higher number in the collector will not provide a higher fraction due to the working hours in the morning and the need for idle operation of boilers to reach the setpoint of 55° C. As can be seen in Figure 13; the auxiliary heat production is very low but not zero when the energy delivery by the solar collector is more than the energy needed for the system. The non-zero value refers to the energy demanded for the setpoint target. The graph shows the rate in June. For the cold season, the proportion of the auxiliary boilers increase.

With this installation, the maximum annual of 82% of solar fraction is achievable.

Table 8. Maximum annual energy saving with ten solar collectors in case 3

Annual energy saved (year 1)	18,961 kWh
Solar fraction (year 1)	0.82
Aux with solar (year 1)	4,060.4 kWh
Aux without solar (year 1)	23,199.7 kWh

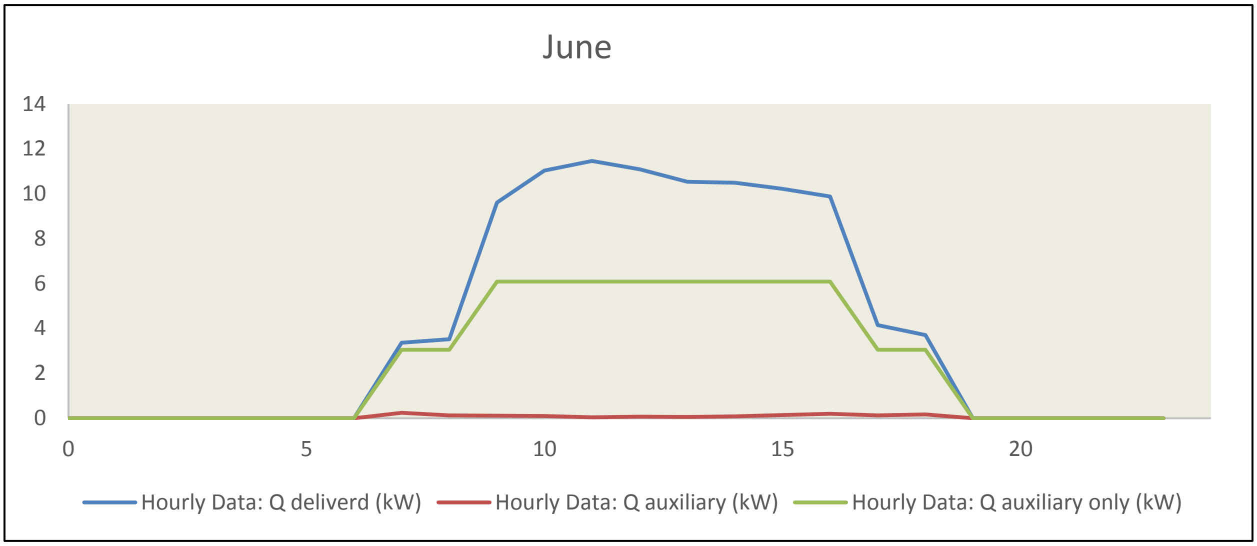

Figure 14. Maximum capacity of hot water production, provided by the ten solar collectors, and the need for other auxiliary boilers in case 3

Case 4: Щастливо детство (Shtastlivo detstvo)

This kindergarten has a flat roof with a total area of 1200 m^2. The water consumption is 8.1 m^3 per day. This gives a hot water consumption of 2430 liters.

Figure 15. The front view of case 4

Figure 16. The top view and possible installation length of case 4

In the first scenario, to provide at least 55% of the hot water production, the system should produce 1336 liters of hot water at 55° C per day. Eight solar collectors integrated into one row can provide 58% of the annual energy needed for hot water.

Table 9. Annual energy saving with eight solar collectors in case 4

Annual energy saved (year 1)	27,206 kWh
Solar fraction (year 1)	0.58

Aux with solar (year 1)	19,562.8 kWh
Aux without solar (year 1)	46,979.4 kWh

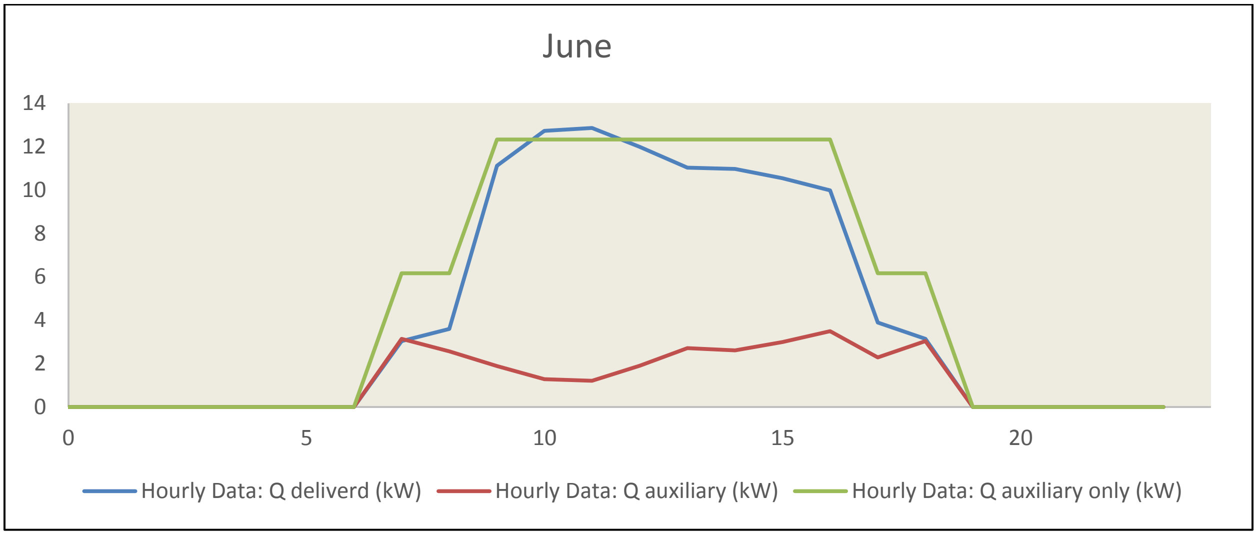

Figure 17. Daily power needed for hot water production, provided by the eight solar collectors, and the need for other auxiliary boilers in case 4

With 32 meters available on top of the roof, installing 16 solar collectors in one row is possible. The production capacity and energy savings will be upgraded to 75% with this layout.

Table 10. Annual energy saving with sixteen solar collectors in case 4

Annual energy saved (year 1)	35,148 kWh
Solar fraction (year 1)	0.75
Aux with solar (year 1)	11,627.4 kWh
Aux without solar (year 1)	46,979.4 kWh

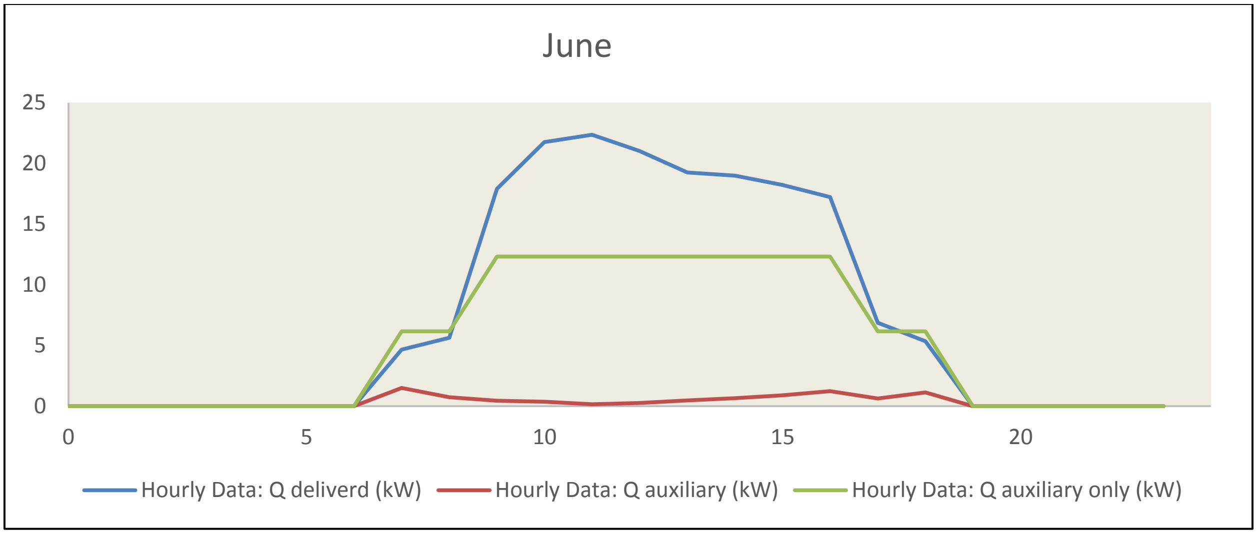

Figure 18. Maximum capacity of hot water production, provided by the 16 solar collectors, and the need for other auxiliary boilers in case 4

Case 5: Вечерница (Vecernitza)

This kindergarten has a flat roof with a total area of 350 m^2. The water consumption is 4.1 m^3 per day. This gives a hot water consumption of 1230 liters.

Figure 19. The front view of case 5

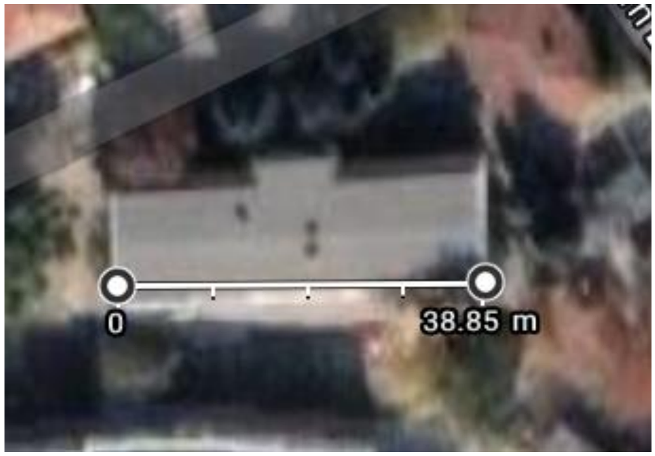

Figure 20. The top view and possible installation length of case 5

With four collectors, the solar heat system provides 57% of the annual hot water energy demand, which is a bit higher than the requirement of 55%. This means the system can provide more than 670 liters of hot water at 55° C per day.

In June, the solar heater can produce 5 out of 6 kW of the heat for hot water during the pick hours. The boiler capacity of one kW is enough for summer days. For winter days, this is almost in contrast. Boilers provide about 80% of energy, and solar collectors produce about 20%. This is shown in Figure 20 and Figure 21.

Table 11. Annual energy saving with four solar collectors in case 5

Annual energy saved (year 1)	13,607 kWh
Solar fraction (year 1)	0.57
Aux with solar (year 1)	9,977.4 kWh
Aux without solar (year 1)	23,779.7 kWh

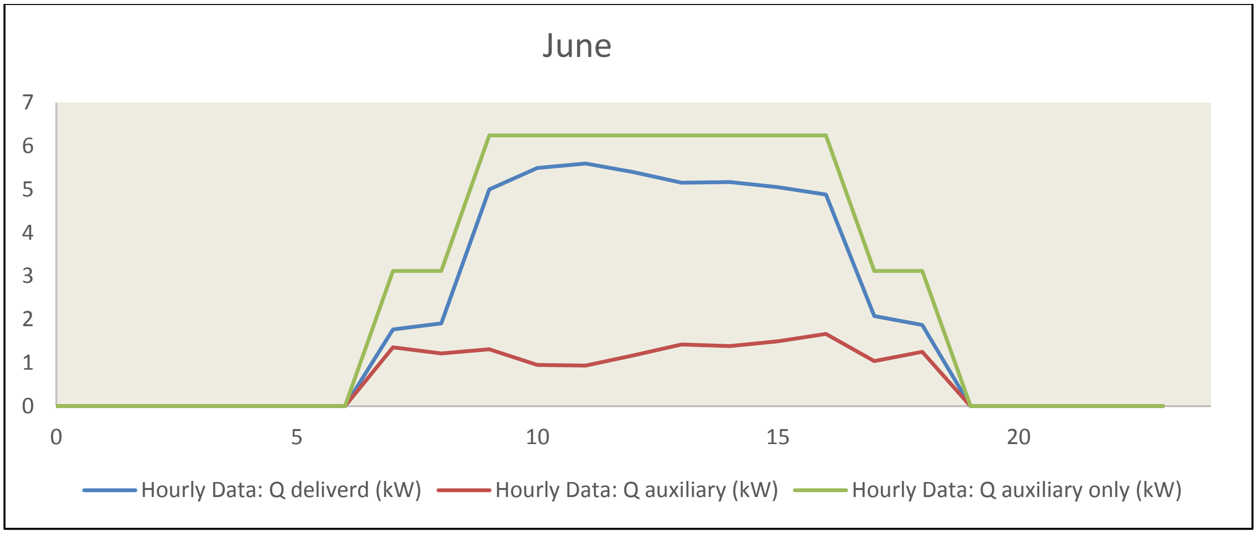

Figure 21. Daily power needed for hot water production, provided by the four solar collectors, and the need for other auxiliary boilers in case 5

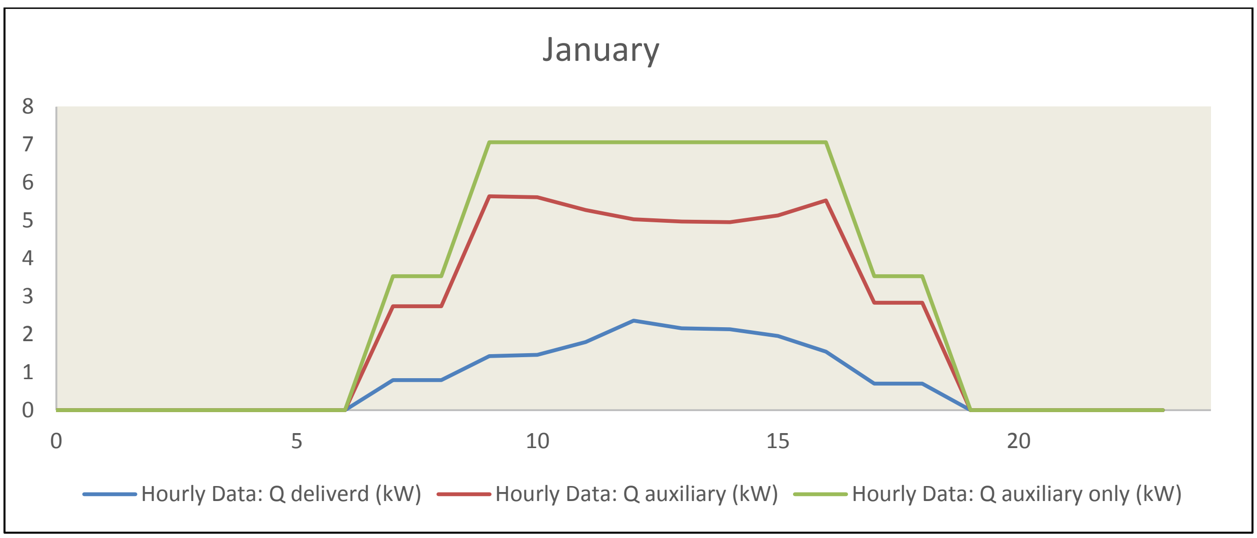

Figure 22. Daily power needed for hot water production, provided by the four solar collectors, and the need for other auxiliary boilers in case 5 for January

By increasing the number of collectors to 7, the solar fraction reaches 75 %. Although there is enough space to install more collectors, the addition gives just 1-2 percent more fraction.

Table 12.Annual energy saving with seven solar collectors in case 5

Annual energy saved (year 1)	17,772 kWh
Solar fraction (year 1)	0.75
Aux with solar (year 1)	5,834.4 kWh
Aux without solar (year 1)	23,779.7 kWh

Case 6: Алени макове (Aleni Makove)

This kindergarten has a flat roof with a total area of 285m^2. The water consumption is 5.4 m^3 per day. This gives a hot water consumption of 1620 liters.

Figure 23. The front view of case 6

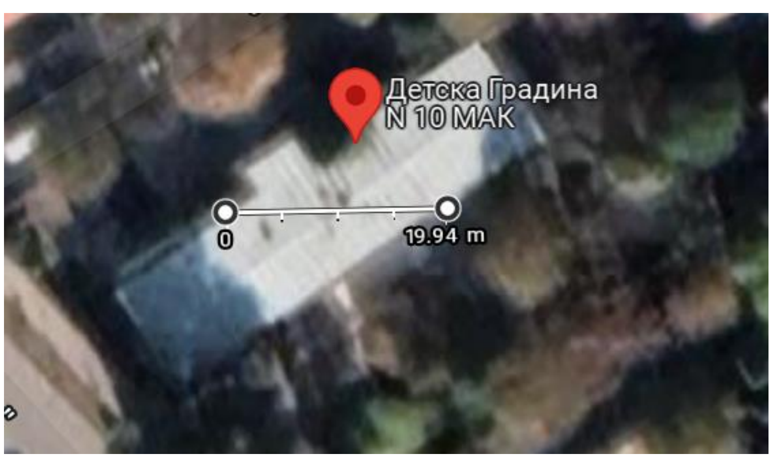

Figure 24. The top view and possible installation length of case 6

The solar heat system provides 56% of the annual hot water energy demand with five collectors. This means the system can provide more than 891 liters of hot water at 55° C per day.

Table 13. Annual energy saving with five solar collectors in case 6

Annual energy saved (year 1)	17,510 kWh
Solar fraction (year 1)	0.56
Aux with solar (year 1)	13,607.7 kWh
Aux without solar (year 1)	31,319.6 kWh

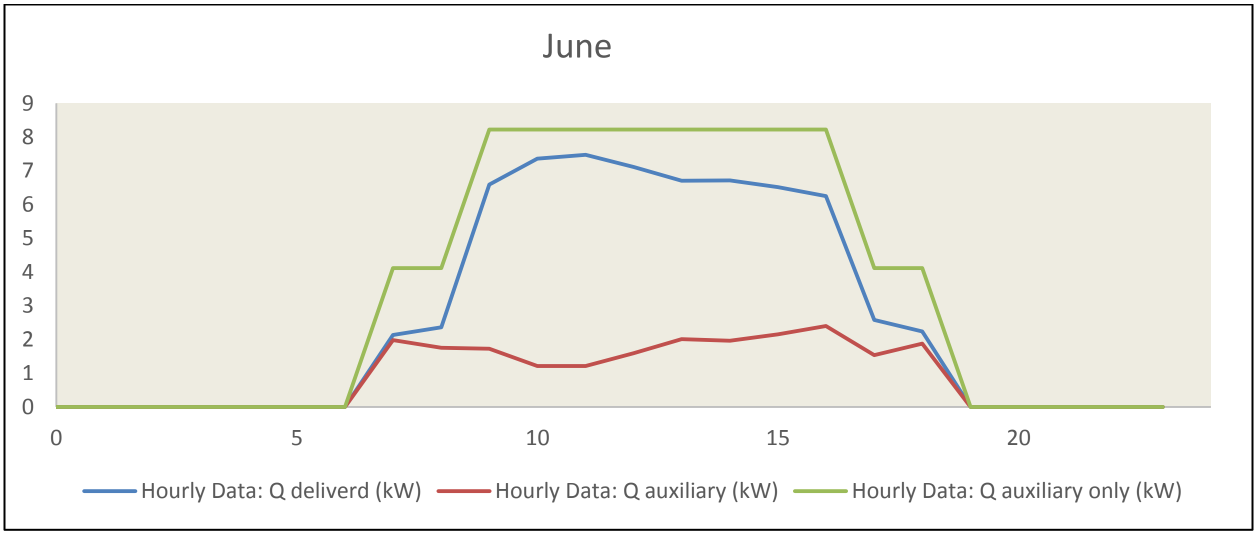

Figure 25. Daily power needed for hot water production, provided by the five solar collectors, and the need for other auxiliary boilers in case 6

By using the total available area, ten collectors can be installed. It means that by doubling the number of collectors, the solar fraction increases up to another 20% and reaches 77% of the total energy demand for hot water.

Table 14. Annual energy saving with ten solar collectors in case 6

Annual energy saved (year 1)	24,022 kWh

Solar fraction (year 1)	0.77
Aux with solar (year 1)	7,121.9 kWh
Aux without solar (year 1)	31,319.6 kWh

Case 7: Детски свят (Detski sviayt)

This kindergarten has a flat roof with a total area of 330 m^2. The water consumption is 7.5 m^3 per day. This gives a hot water consumption of 2250 liters.

Figure 26.The front view of case 7

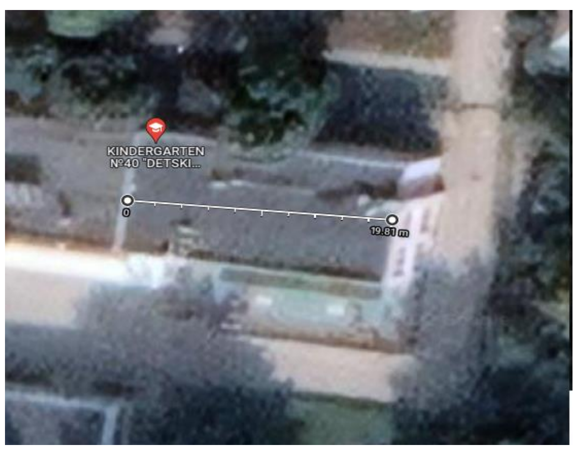

Figure 27.The top view and possible installation length of case 7

The solar heat system with seven collectors provides 56% of the annual hot water energy demand with seven collectors. This means the system can provide more than 1237 liters of hot water at 55° C per day.

Table 15. Annual energy saving with seven solar collectors in case 7

Annual energy saved (year 1)	24,549 kWh
Solar fraction (year 1)	0.56
Aux with solar (year 1)	18,740.9 kWh
Aux without solar (year 1)	43,499.5 kWh

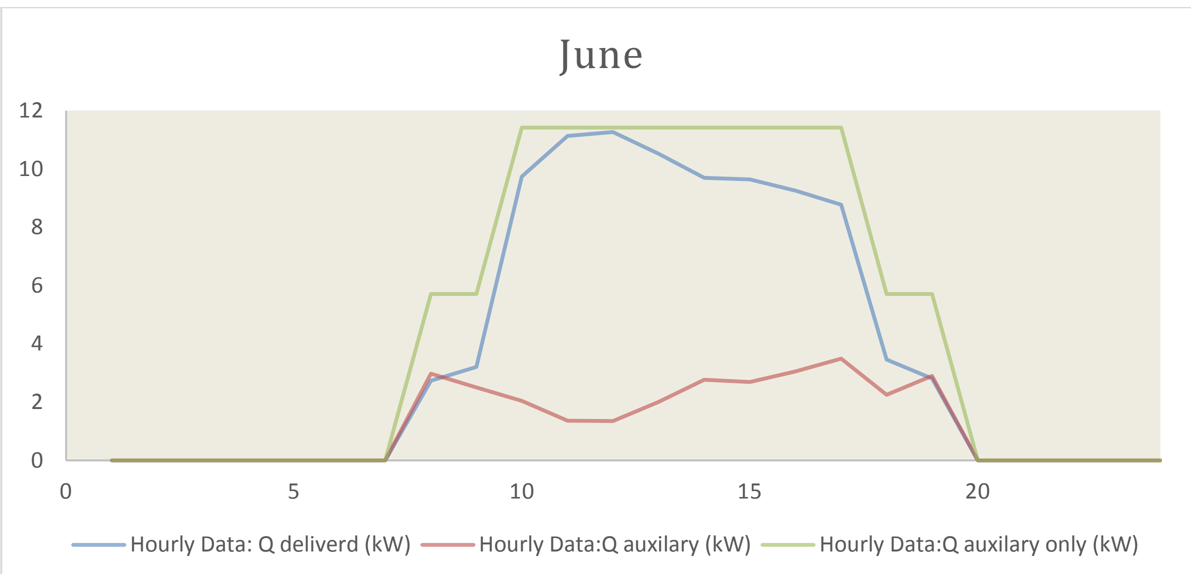

Figure 28. Daily power needed for hot water production, provided by the seven solar collectors, and the need for other auxiliary boilers in case 7

With 20 meters available on top of the roof, installing 10 solar collectors in one row is possible. The production capacity and energy savings will be upgraded to 66% with this layout.

Table 16. Annual energy saving with ten solar collectors in case 7

Annual energy saved (year 1)	28,864 kWh
Solar fraction (year 1)	0.66
Aux with solar (year 1)	14,428.6

	kWh
Aux without solar (year 1)	43,499.5 kWh

Case 8: Синчец (Sintchetz)

This kindergarten has a sloping roof. The water consumption is 0.1 m^3 per day. This gives a hot water consumption of 30 liters.

Figure 29. The front view of case 8

Figure 30. The top view and possible installation length of case 8

The solar heat system provides 71% of annual hot water energy with one collector.

In June, the solar heater can produce 100% of the heat for hot water during the pick hours. Boilers provide about 80% of energy on winter days, and solar collectors produce about 20%. This is shown in Figure 20 and Figure 21.

Table 17. Annual energy saving with one solar collector in case 8

Annual energy saved (year 1)	414 kWh
Solar fraction (year 1)	0.71
Aux with solar (year 1)	58.5 kWh
Aux without solar (year 1)	580.0 kWh

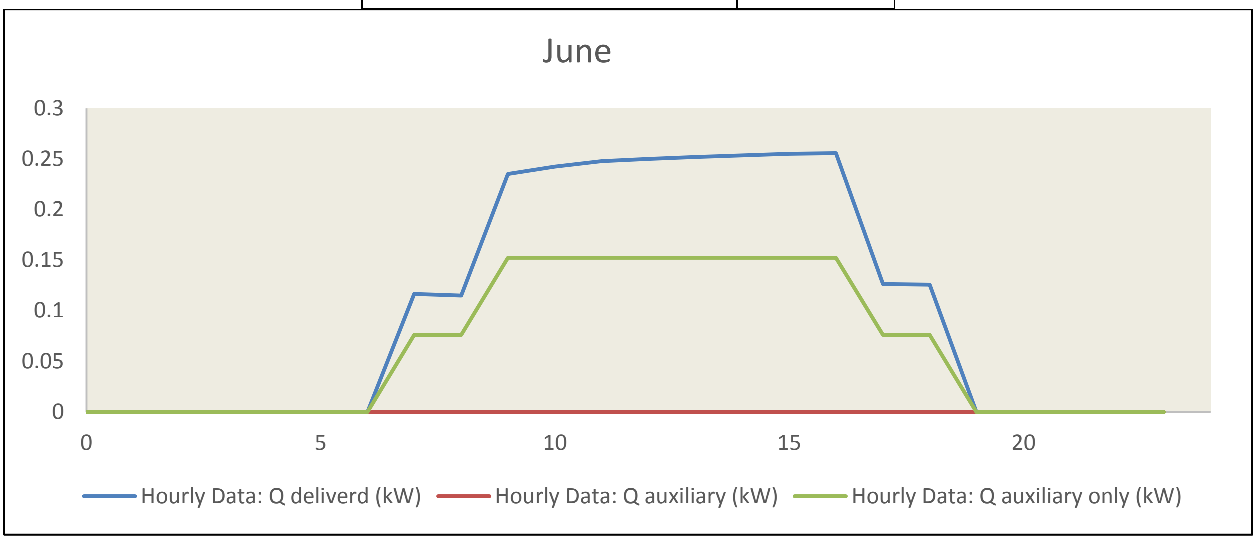

Figure 31. Daily power needed for hot water production, provided by the one solar collector, and the need for other auxiliary boilers in case 8

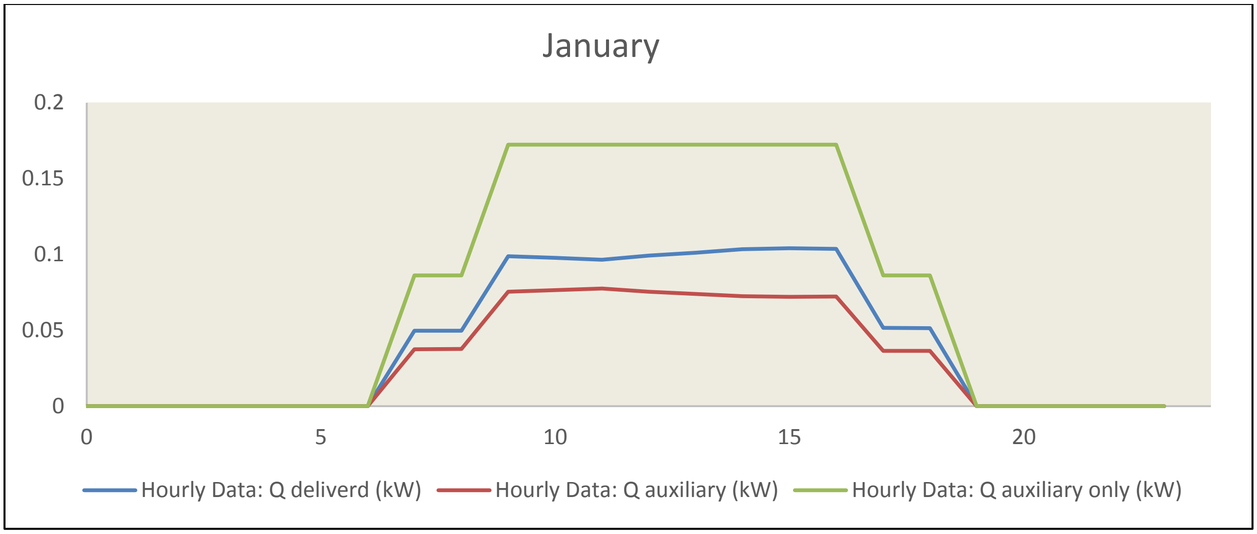

Figure 32.Daily power needed for hot water production, provided by the one solar collector, and the need for other auxiliary boilers in case 8 on January

Case 9: Усмивка (Usmivka_1)

This kindergarten has a flat roof with a total area of 325 m^2. The water consumption is 0.4 m^3 per day. This gives a hot water consumption of 120 liters.

Figure 33. The front view of case 9

Figure 34. The top view and possible installation length of case 9

One collector is enough to produce 120 Liters per day to cover the least of 55%. With one collector size of about 5m2, the system provides 70% of annual energy for the hot water. More detail is shown in Table 14 and Figure 29.

Table 18. Annual energy saving with one solar collector in case 9

Annual energy saved (year 1)	1,628 kWh
Solar fraction (year 1)	0.70
Aux with solar (year 1)	553.6 kWh
Aux without solar (year 1)	2,320.0 kWh

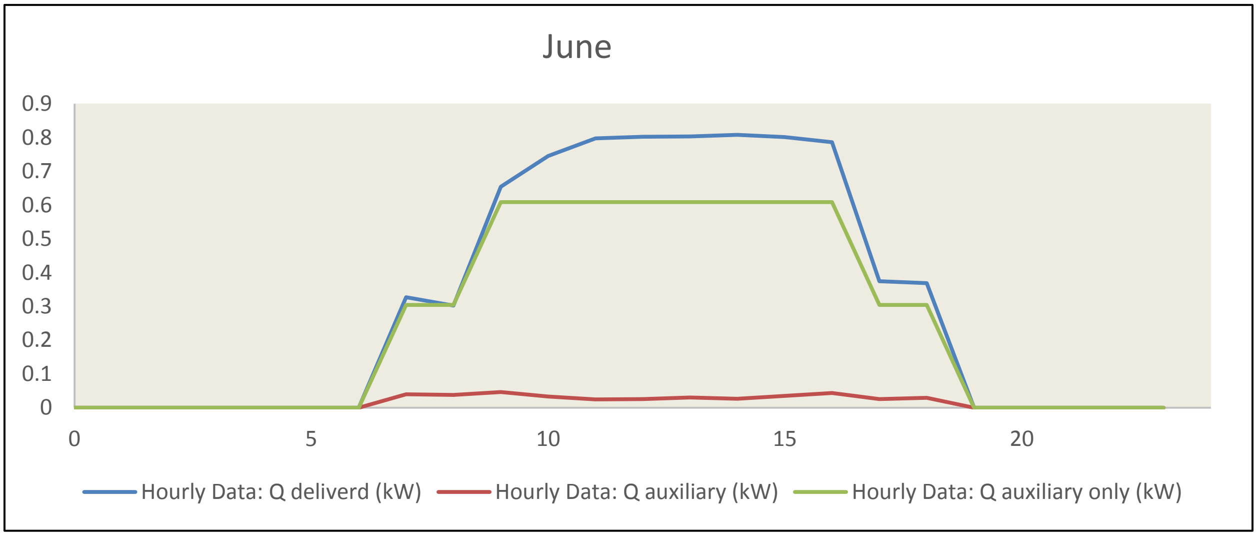

Figure 35. Daily power needed for hot water production, provided by the one solar collectors, and the need for other auxiliary boilers in case 9

Case 10: Усмивка (Usmivka_2)

This kindergarten has a flat roof with a total area of 408 m^2. The water consumption is 1.0 m^3 per day. For producing 300 Liters of hot water per day to cover the least 55%, two collectors are enough. With two collectors of about $5m^2$, the system provides 73% of annual energy for the hot water while one collector provides just about 50%.

Table 19. Annual energy saving with two solar collectors in case 10

Annual energy saved (year 1)	4,243 kWh
Solar fraction (year 1)	0.73
Aux with solar (year 1)	1,404.4 kWh
Aux without solar (year 1)	5,799.9 kWh

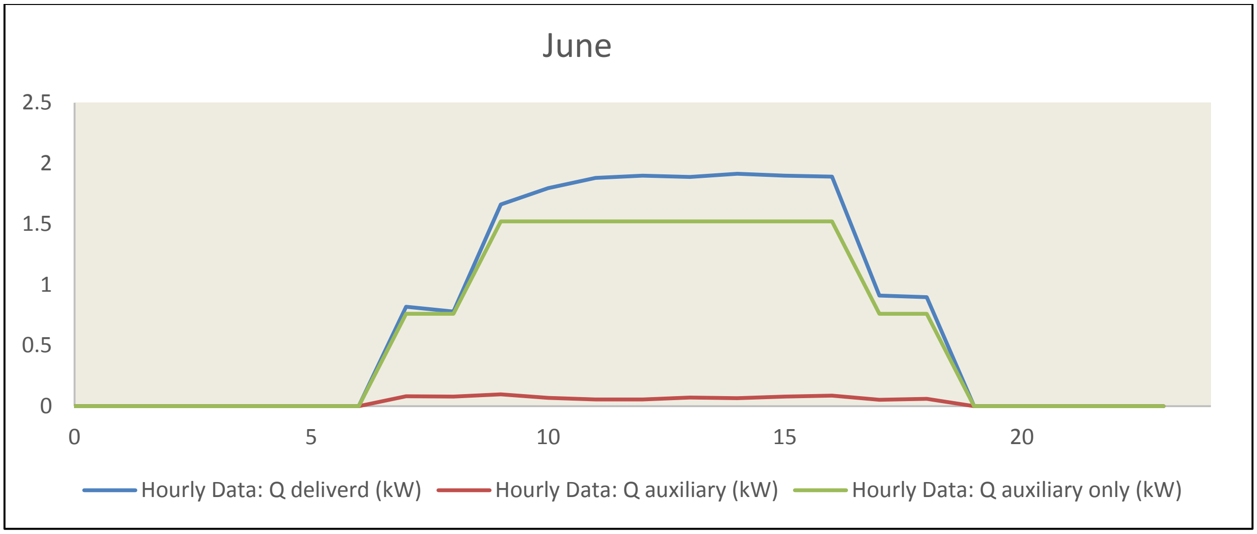

Figure 36. Daily power needed for hot water production, provided by the two solar collectors, and the need for other auxiliary boilers in case 10

Summary and conclusion

A short representation of all the cases is shown in Table20. A summary of the available area, the flow rate requirements and maximum potential of collectors. The table shows the total available area, the collector area for 55% of hot water production, and the hot water consumption in the kindergartens. Hot water production percentage by collector shows that all the cases have the capacity of proving the minimum 55% of the hot water based on the project plan. In addition, for all the cases, a second scenario as the maximum capacity has been shown. For the cases with more than 70% of hot water production with solar collectors, the second scenario is not presented.

Table 20. A summary of the available area, the flow rate requirements and maximum potential of collectors

Case studies	Total area(m^2)	Collector area (length)	Hot water consumption(liter)	Hot water production by collectors (%)	Maximum potential of collectors (%)
Case 1	265	14	1320	56	73
Case 2	400	10,4	1830	57	57
Case 3	350	20	1200	58	82
Case 4	1200	32	2430	58	75
Case 5	350	38	1230	57	75
Case 6	285	20	1620	56	77

Case 7	330	20	2250	56	66
Case 8	-	-	30	71	-
Case 9	325	20	120	70	-
Case 10	408	-	300	73	-

A basic modeling result for Case 2 as an example shows that by installing PV modules on the entire available roof area, annual energy production increases up to 63 MWh, with a maximum capacity of 30 kW. While installing collectors in available roof length, annual energy production was 20 MWh, with a maximum capacity of 9 kW. Thus, a solution for even more efficient savings is installing PV panels than the collectors. However, the PV panels cost more and increase the complexity of the power system.

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