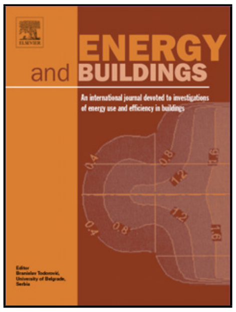

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Author: Miloš Banjac

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Achieving Sustainable Work of the Heat Pump with the Support of an Underground Water Tank and Solar Collectors

Professor Miloš Banjac, PhD

Department of Thermodynamics, Faculty of Mechanical Engineering, University of Belgrade
Kraljice Marije 16, Belgrade, Serbia
mbanjac@mas.bg.ac.rs

Abstract

This paper deals with the methodology of sizing a sustainable heating-cooling system, which consists of a heat pump, thermo-solar collectors and underground water tank, as a seasonal thermal energy storage. The methodology is based on successive and coupled energy balancing of all system elements for time intervals of one hour, during one representative calendar year. The starting assumption for the calculation contains the size of the underground storage tank, its burial depth, the size of building that is heated or cooled, the temperature of air in the building, To make the calculation, it is necessary to know the so called dynamic boundary conditions during a calendar year, comprising the following: hourly outdoor air temperature, hourly insolation (received solar radiation energy) and hourly temperature of the ground surface. The calculation result is the size of the thermal-solar collectors surface, which will ensure the sustainability of the system, i.e. it will ensure that after one year of operation this system is restored to the original conditions, without disturbing natural environment in which it is used.

For the purpose of presenting the methodology and checking the influence of individual parameters of the system's operation, a numerical simulation was performed and required surfaces of thermo-solar collectors were determined for one of the system models. Analyses of the influence of the underground tank burial depth, tank size and the initial water temperature in the tank on the required size of thermal-solar collectors were also performed.

Keywords: water source heat pump, sustainable; underground water tanks, thermal-solar collectors, solar energy

1. Introduction

Today, due to the growing environmental threats, the use of renewable energy sources has become increasingly important. Besides their basic characteristic - renewability, economic reasons may often have a decisive influence on their implementation. In other words, it is frequently the case that the use of renewable energy sources, in addition to reducing the harmful impact on the environment, substantially reduces the operating costs of particular systems. Also, it frequently happens that the over-exploitation of these resources disrupts the natural mechanisms through which these sources are recovered and returned to their original state, undermining their characteristic renewability.

Generally speaking, it can be said that the technological development of civilization came to the end of an era when fossil fuels, conventional or non-renewable sources of energy, cannot be considered as the basis for planning future development and that we are living in times when energy technologies are rapidly changing. More and more, consumers and companies are turning to the usage of renewable energy sources and technologies that provide their use. Besides the basic property of these sources - the property of renewability it is of great importance that they also fulfil an other important condition during their use - the condition of sustainability. Namely, it often happens that the use of energy resources declared as renewable (biomass, hydropower, geothermal energy), their unplanned or excessive exploitation, distorts their surroundings and disrupt natural mechanisms that allow these sources to recover and return to their original state. In that way, the utilization of these resources is jeopardized and, in some cases, their renewability is permanently violated.

Geothermal energy is a renewable energy source, which has always attracted an increased interest, especially when it appears in the forms of hot water and steam. Examples of its use go back to the very beginning of civilization. However, in the case of thermal energy of dry ground layers, regardless of their theoretically unlimited heat capacity, their utilization was not possible until recently because of their low temperature. Only in recent decades, with the development and mass production of heat pumps, this renewable energy source has been experiencing its full affirmation.

But, the new problem related to the sustainability of these sources – the so-called issue of thermal exhaustion of the ground - has emerged with the first year of their use. To some extent, the problem has been overcome by the use of these systems for cooling buildings in the summer, when the heat energy collected from the conditioned space has been accumulated in the ground. However, it turned out that this thermal energy is not sufficient to keep the system fully sustainable. It just delayed the problem of soil thermal exhaustion for some time. In order to overcome this problem, the idea of inclusion of an the additional sub-system in the heat pump system arose– the idea of a thermal energy storage - underground tank with water, and solar collectors - that will supply this thermal tank with additional thermal energy [1-4].

Until now, mathematical modelling of such systems [1-7] referred only to obtaining mathematical relations for determination of the temperature field in the soil around the tank under steady state heat load. Considering that the sustainability of the system still has the key position for its operation, this paper presents a methodology for determining the necessary size of thermo-solar collectors, which will ensure the sustainable work of the cooling-heating heat pump system with an underground thermal energy storage water tank. In other words, this means that in case of solar collectors' sizing in accordance with the methodology presented in this paper, it would ensure that after one year of operation, this system would be restored to its original condition, without disturbing natural environment in which it is used.

For the purpose of presenting the methodology and checking the influence of individual parameters of the system's operation, a numerical simulation was performed and required surfaces of thermo-solar collectors were determined for one of the system models. In particular, analyses of the influence of underground tank burial depth, as well as the tank size and the initial water temperature in the tank on the required size of thermal-solar collectors were also performed.

2. Physical Model

Water-water heat pump system was chosen as the model space heating-cooling system. This system uses a spherical tank having the volume of 200 m^3, completely buried in the ground and filled with water, as a heat source in winter time, and a heat sink in summer time. It was assumed that the heating-cooling system should provide air temperature of 20°C in the model houses – "C" energy classes (annual energy consumption for space heating per m^2 is 74 kW/ m^2a), having 170 m^2 heating area, located in Belgrade - throughout the calendar year.

Because of the climate conditions in this region, and greater annual needs for thermal than for cooling energy, it was predicted that the lacking heat energy in a tank should be compensated with solar energy collected with thermal-solar collectors directly linked to the buried tank (Figure 1). The thermal storage is not active during the transitional periods between heating and cooling seasons and during these periods there is no heat transfer between solar panels and underground thermal energy storage . Solar energy is collected throughout the year except in the period from 16th April to 8th May, because it would only reduce the cooling capacity of the underground tank. During the whole year, the corresponding heat transfer between the tank (water) and the soil is achieved, depending on the current temperature of water in the reservoir and the temperature of the soil (Figure 2).

As already mentioned, the basis of the methodology for dimensioning the sustainable heating-cooling system is the coupled energy balance for three sub-systems: heating demands for model building, energy balance of underground tank and energy balance of solar collectors. Due to the lack of exact solutions of differential equations which describe the transient temperature field around the sphere with variable heat transfer buried in a semi-infinite medium, this non-stationary problem has been solved numerically by successive calculations for time intervals of one hour. The time interval of one hour was chosen because, for this time interval, changes of water temperature and temperature of the ground surface are sufficiently small that the process could be treated as quasi-stationary.

At the same time, non-stationary feature of the calculation is provided by taking into account the dynamic boundary conditions, so-called hourly value of all influential external parameters:

- hourly temperature of the outside air,
- hourly temperature of the earth's surface and
- hourly insolation - solar radiation energy

In other words, this transient heat problem was solved by a 3x8760 calculations for quasi-stationary conditions of the three subsystems, whose effect is mutually coupled to the energy balance of the underground storage tank.

According to experimental investigation [8-11] and manufacturers' data [12,13], it was assumed for the purposes of this calculation that the coefficient of performance of heat pumps for heating COP_{H} and coefficient of performance for cooling COP_{C} can be expressed as a linear function of difference between water temperature in the tank θ_{w} and ambient air temperature (designed temperature of the air inside the building) θ_{i}. Since the coefficient of performance of heat pumps for heating is expressed as: $COP_{\mathrm{H}} = 3,5 - 0,125 \cdot (\theta_{\mathrm{i}} - \theta_{\mathrm{w}})$ for $4°\mathrm{C} < \theta_{\mathrm{w}} < 25,6°\mathrm{C}$, and for $\theta_{\mathrm{w}} \geq 25,6°\mathrm{C}$, is $(COP_{\mathrm{H}})_{\max} = 4,2$, and the coefficient of performance for cooling is expressed as: $COP_{\mathrm{C}} = 3,4 - 0,04 \cdot (\theta_{\mathrm{w}} - \theta_{\mathrm{i}})$ for $T_{\mathrm{w}} > 20°\mathrm{C}$ and $(COP_{\mathrm{C}})_{\max} = 3,4$ for $8°\mathrm{C} < \theta_{\mathrm{w}} \leq 20°\mathrm{C}$.

3. Energy Balances for Heat Storage

The crucial and definitely the most sensitive part of the methodology is not only the definition, but also the way of calculating the individual members of the energy balance for the underground thermal energy storage.

The energy balance for the underground thermal energy storage - hot water tank - for a period of one hour can be expressed as follows (Figure 2):

$$Q_{(+\mathrm{hp}),1h} + Q_{+\lambda,1h} + Q_{\mathrm{sol},1h} = \Delta U + Q_{-\lambda,1h} + Q_{(-\mathrm{hp}),1h} \qquad (1)$$

where:

$Q_{(+\mathrm{hp}),1h}$ - amount of heat received by the water in the tank from the heat pump for one hour (cooling mode),

$Q_{+\lambda,1h}$ - amount of heat received by the water in the tank by conduction from the surrounding ground;

$Q_{\mathrm{sol},1h}$ - amount of heat received by the water in the tank from solar collectors and which originates from solar energy,

$Q_{(\mathrm{-hp}),1h}$ - amount of heat delivered by the water in the tank to the heat pump for one hour (heating mode);

$Q_{-\lambda,1h}$ - amount of heat delivered by the water in the tank by conduction to the surrounding ground;

ΔU - the change of internal energy of the water in the tank, which is defined as:

$$\Delta U = \rho_{\mathrm{w}} \cdot V_{\mathrm{w}} \cdot c_{p\mathrm{w}} \cdot \Delta\theta_{\mathrm{w}} \qquad (2)$$

where:

ρ_{w} - the density of water (for the calculation, the value of water density for the assumed range of operating temperatures $\rho_{\mathrm{w}} = 998{,}2\ \mathrm{kg/m^3}$)

V_{w} - tank volume

$c_{p\mathrm{w}}$ - specific water heat capacity o at constant pressure (for the calculation, $c_{p\mathrm{w}} = 4{,}186\ \mathrm{kJ/(kg\ K)}$),

$\Delta\theta_{\mathrm{w}}$ - changes of water temperature in the tank

Somewhat simpler equation (1) can be written as:

$$Q_{\mathrm{in},1h} = \Delta U + Q_{\mathrm{out},1h} \tag{3}$$

where:

$Q_{\mathrm{in},1h}$ - the total amount of heat received by the water in the tank in one hour,

$Q_{\mathrm{out},1h}$ - the total amount of heat delivered by the water in the tank in one hour;

Having in mind that the calculation of the thermal energy of the underground storage is performed in successive hourly energy budgeting and for a single calendar year, or more precisely from 15th October at 0:00 pm to 14th October at 24 h in the following year, with different energy needs of model houses in different time periods and thus fundamentally different directions of heat flow, the calculation is carried out for four periods within the above stated time span, i.e.:

1. heating season (from 15th October to April 15th)
2. spring transition period (from 16th April to 8th May)
3. cooling season (from 9th May to 16th September)
4. autumn transition period (from 17th September to 14th October).

According to this classification, the total hourly heat $Q_{\mathrm{in},1h}$ and $Q_{\mathrm{out},1h}$ in some periods were determined as:

$$Q_{\mathrm{in},1h} = \begin{cases} Q_{\mathrm{sol},1h} & \text{heating period} \\ Q_{+\lambda,1h} & \text{transition period (springtime)} \\ Q_{(+\mathrm{hp}),1h} & \text{cooling period} \\ Q_{\mathrm{sol},1h} & \text{transition period (autumn)} \end{cases} \tag{4}$$

that is

$$Q_{\mathrm{out},1h} = \begin{cases} Q_{(-\mathrm{hp}),1h} + Q_{-\lambda,1h} & \text{heating period} \\ 0 & \text{transition period (springtime)} \\ Q_{-\lambda,1h} & \text{cooling period} \\ Q_{-\lambda,1h} & \text{transition period (autumn)} \end{cases} \tag{5}$$

The components of the heat flow $Q_{\mathrm{in},1h}$ and $Q_{\mathrm{out},1h}$ in the respective periods are shown in the Figure 2.

Hourly heat delivered to the water in the tank, which originates from solar energy $Q_{\mathrm{sol},1h}$, from thermo-solar collectors, determined on the basis of measured and processed hourly values of the insolation (hourly irradiation) $q_{\mathrm{sol},1h}$, [15], efficiency of the solar collector η and its assumed surface area A:

$$Q_{\mathrm{sol},1h} = q_{\mathrm{sol},1h} \cdot \eta \cdot A \tag{6}$$

The characteristic curve of efficiency for presumed direct flow-through evacuated-tube solar collector was described by equation [14]:

$$\eta = \eta_0 - k \cdot \Delta\theta_{\mathrm{abs}} / G \tag{7}$$

where

$\eta_0 = 0.78$ themaximum efficiency at $\Delta\theta_{\mathrm{abs}} = 0°\mathrm{C}$

$k = 210$ W/m^{2}K - heat loss coefficient,

$\Delta\theta_{\mathrm{abs}}$ - average temperature difference between absorber and air

G - available insolation (W/m^2)

As example of the dates used in the calculation, hourly irradiation $q_{\mathrm{sol},1h}$ for the month of September, i.e. for the 1st day of September are showed in Figures 3 and 4 respectively [15].

Monthly insolation in the Belgrade area is shown in Figure 5 [15].

Hourly heat delivered by the water in the tank by conduction to the surrounding ground $Q_{-\lambda,1h}$, and vice versa $Q_{+\lambda,1h}$, when the water temperature drops below the temperature of the surrounding ground, is determined by the expression for stationary heat conduction in the case of spheres buried in isotropic semi-infinite medium, Figure 6, [16]:

$$Q_{\lambda,1h} = 4 \cdot \pi \cdot R \cdot \lambda_{\mathrm{soil}} \frac{\left(\theta_{\mathrm{w}} - \theta_{\mathrm{soil},1m}\right)}{1 + \dfrac{R}{2 \cdot h}} \tag{8}$$

where:

R - radius of the spherical tank;

λ_{soil} - thermal conductivity of the soil;

h - burial depth of the tank, measured from the centre of the sphere to the depth of the soil of 1 m;

$\theta_{\mathrm{soil,1m}}$ - soil temperature at a depth of 1 m.

The value of thermal conductivity of the soil λ_{soil} depends on the type and composition of the soil. Because of the introduced assumption of soil isotropy, it is considered that the thermal conductivity value is constant throughout the soil. In the considered case, in accordance with the soil characteristics in our region, it was assumed that $\lambda_{\text{soil}} = 1,7\ \text{W/(m K)}$.

Data for hourly temperature of the soil at the depth of 1 m from the surface, collected in the period from 1st January 1997 to 31th December 2006 for Belgrade region, were taken over from the Republic Hydro-meteorological Service of Serbia, [15] Figure 7. By averaging and discounting these values for a period of one year, the hourly changes of soil temperature at the depth of 1 m were established for the so-called representative year.

Hourly heat $Q_{\text{(-hp)},1h}$, delivered by the water from the tank during the heating period to the working fluid of the heat pump, based on the adopted values of COP_{H} of the heat pump can be calculated as:

$$Q_{\text{(-hp)},1h} = Q_{\text{heat.load},1h}\left(1 - \frac{1}{COP_{\text{H}}}\right), \tag{9}$$

where:

$Q_{\text{heat.load},1h}$ = heat that compensates the heating load of the building. The value of the amount of hourly heat for a given model is defined as [17,18]:

$$Q_{\text{heat.load},1h} = \sum_{i}\left(F_{xi} \cdot U_i \cdot A_i\right)\left(\theta_{\text{i}} - \theta_{\text{e}}\right) + H_V\left(\theta_{\text{i}} - \theta_{\text{e}}\right) \tag{10}$$

where:

F_{xi} - the temperature correction factor for the external walls and windows $F_{x,\text{wall}} = F_{x,\text{win}} = 1$, for the ceiling $F_{x,\text{ceil}} = 0,8$ and for the floor $F_{x,\text{floor}} = 0,5$.

U_i – overall heat transfer coefficient for outer walls U_{wall} = 0,4 W/(m^{2}K), overall heat transfer coefficient for windows U_{win} = 1,5 W/(m^{2}K), overall heat transfer coefficient for the floor U_{flor} = 0,4 W/(m^{2}K), overall heat transfer coefficient for the celling U_{cell} = 0,4 W/(m^{2}K)

A_i - surface of the model-house *i*-th envelope element of model house (walls, windows, celling and floor);

θ_{e} - external air temperature

H_V - overall coefficient of heat transfer by ventilation, adjusted for the indoor-outdoor temperature difference, calculated as

$$H_V = \rho_a \cdot c_a \cdot V_a \cdot n \tag{11}$$

where:

$\rho_a \cdot c_a =$ the heat capacity of air per volume, expressed in joules per cubic metres per kelvin $\rho_a \cdot c_a = 1\ 200\ \text{J/(m}^3\text{K)}$;

V_a - inside volume of building;

n - number of air exchanges per hour

The first member of equation (10) represents the hourly transmission heat losses, while the second member is the hourly ventilation heat loss for the model house.

Besides the above mentioned assumptions and the previously defined coefficients, the calculation of heat of the proposed model-house was also made with the assumption that the model-house is a two-level house, of rectangular basis, with the total floor area $A_{\text{tot}} = 2 \cdot A_{\text{floor}} = 2 \cdot 85 = 170\ \text{m}^2$ and the height of 2.6 m between two floors, as well as that 20% of the outer surface are windows and doors, and that on the basis of the ISO recommended value of the number of air exchanges of 0,7 $\text{m}^3/\text{m}^2\text{h}$, the number of air exchanges per hour for the complete house is $n = 0.3$ exchanges per hour.

Data for hourly temperature of outside air for Belgrade, collected in the period from 1st January 1997 to 31th December 2006 were taken over from the Republic Hydro-meteorological Service of Serbia, [15] Figure 8. By averaging and discounting these values for a period of one year, the hourly changes of temperature of outside air in Belgrade were established for the so-called representative year.

In accordanece with this outside air temperature during the heating season, the Figure 9 shows the heat load of the model house, determined on the basis of the expression (10).

In the calculation of the heat load of the model house, the infiltration losses were not calculated separately. They have been included in the calculation through adopted low value of the heat transfer coefficient.

Hourly heat $Q_{(+\text{hp}),1h}$, that delivers the working fluid of cooling systems (heat pumps) to the water in reservoir as a heat sink during the cooling period, is calculated based on the adopted values of the coefficient of performance of cooling system (COP_{C}):

$$Q_{(+\text{hp}),1h} = Q_{\text{cool.load},1h}\left(1 + \frac{1}{COP_{\text{C}}}\right), \tag{12}$$

where :

$Q_{\text{cool.load},1h}$ – heat flow that compensates cooling needs of the house. For determination of this value, the hourly data for the cooling load for air conditioning of the medium heavy type house, oriented to the south in a representative year were used (from 8 h to 16 h every day), Figure 10, [19].

Since the heat inputs are given per unit area, thermal load is defined as:

$$Q_{\text{cool.load},1h} = q_{\text{cool.load},1h} \cdot A_{\text{tot}} \tag{13}$$

By numerically solving the system of equations (1-10), with the defined size of the solar collectors, it is possible to determine the annually changes in water temperature in the tank from hour to hour. To make the system sustainable, it is necessary that the assumed water temperature in the tank, ensured by the size of the solar collector, is equal to the temperature in the initial moment after one year of the system operation. Therefore, for obtaining the adequate size of solar collectors that will ensure sustainable operation of the system, it was necessary to repeat calculations with the resizing of the surface of solar collectors until the fulfilment of the set conditions.

4. The Simulation Results and their Analysis

After the implementation of the iterative numerical calculation for defined environmental conditions, it is concluded that the physical model becomes sustainable when the surface of the solar collector is $A = 5.0\ \mathrm{m}^2$. The results of changes of the water temperature in the underground storage in this case are shown in the Figure 11. Also, the calculation has shown that in this case the minimum water temperature in the reservoir occurred at the end of the heating season. More precisely, on the 15th April the temperature of water would amount to $\theta_\mathrm{w} = 7.7°\mathrm{C}$, and the highest water temperature would be on 1st September and amount to $\theta_\mathrm{w} = 40.3°\mathrm{C}$.

By varying certain design parameters - the size of the reservoir and the reservoir burial depth, it has been noted that the size of the underground reservoir has a significantly greater effect on the changes in water temperature (Figure 12). The amplitude of temperature fluctuations was reduced with the increasing volume of water tank and smaller size solar collectors could be used to ensure the sustainability of the system. On the contrary, the volume reduction of the tank entails greater fluctuations of the water temperature and larger required surface of area collectors. Thereby, inappropriately small reservoir volume can lead to the occurrence of water freezing in the reservoir.

Burial depth of the tank has a minor effect on the change of tank water temperature (Figure 13). For greater depth, it is necessary to use larger solar collectors and in spite of that the temperature oscillation is smaller.

Correlation between the changes in the soil temperature at a depth of 1 m and water temperature in the tank is shown in the Figure 14. The change in the water temperature curve has a similar shape and follows the curve changes in soil temperature. In comparison with the soil temperature curve, the water temperature curve has time delay and bigger amplitude of temperature oscillations.

5. Conclusion

This paper presents a methodology for dimensioning of an absolute sustainable heating-cooling system which consists of a ground-coupled heat pump assisted with a solar thermal panel system and underground insulated water tank, as a device for thermal energy storage.

Through the determination of the size of thermo-solar collectors, in a model system - a house of 170 m^2 in size, in the climate of Belgrade, besides demonstrating the application of the methodology, the paper also shows that it is possible to achieve sustainability by using thermo-solar collectors that are only a few square meters high.

Performed numerical calculations show that the size of the underground tanks has the greatest impact on the change of tank water temperature, and that the amplitude of temperature oscillations decreases with the increase of the tank volume. Also, it has been shown that the tank burial depth had a minor effect on the change of water temperature in the tank.

Further work on this issue will be directed towards performing a comprehensive techno-economic analysis, which is necessary to determine the amount of energy savings and payback time of such a system. As part of this future analysis, it would be necessary to consider the possibility of using passive cooling as an additional way for saving energy, as well as the use of some phase change material instead of water in the tank.

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Figure_1

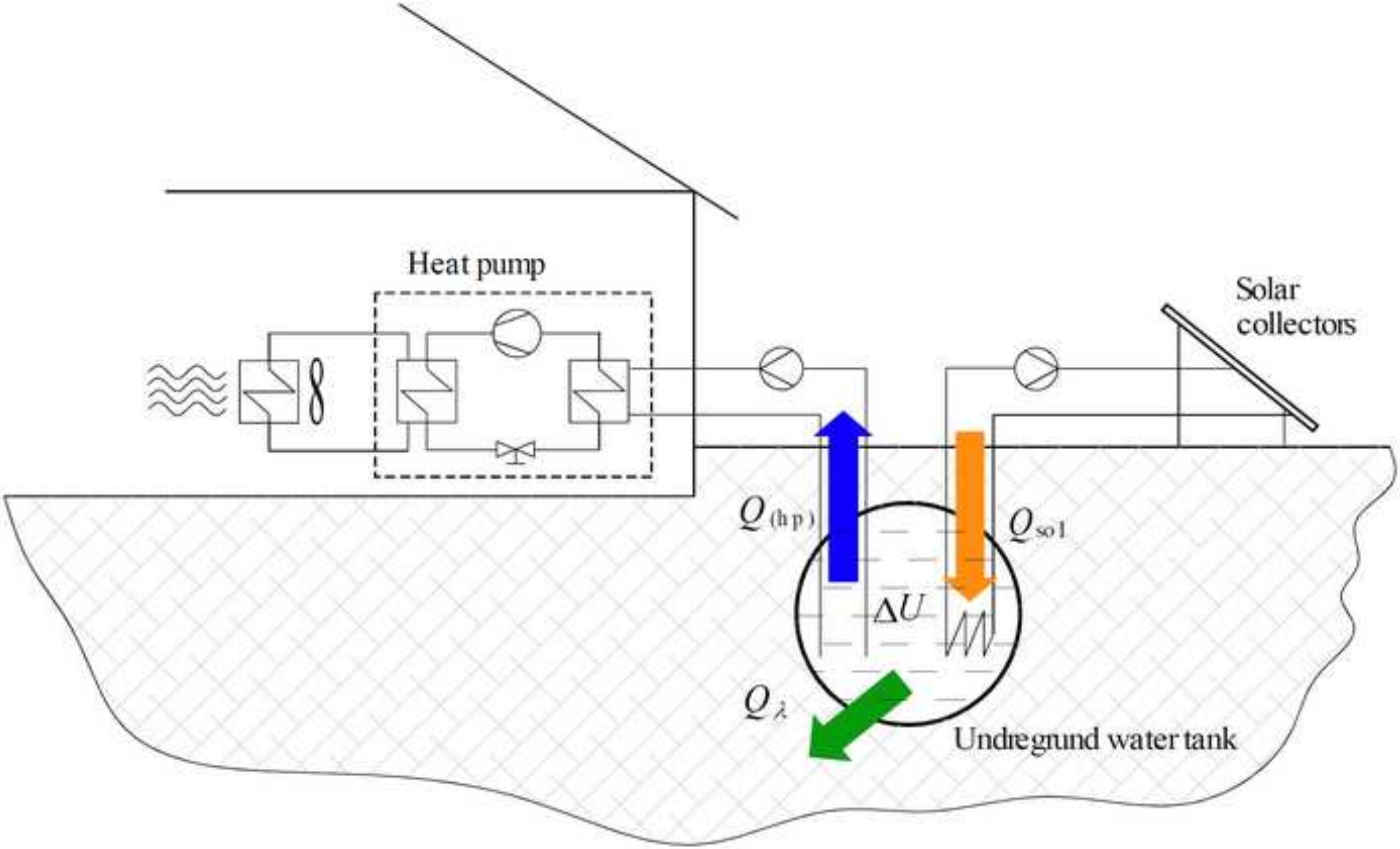

Heat pump
Solar collectors
$Q_{(hp)}$
Q_{sol}
ΔU
Q_{λ}
Undregrund water tank

Figure_2

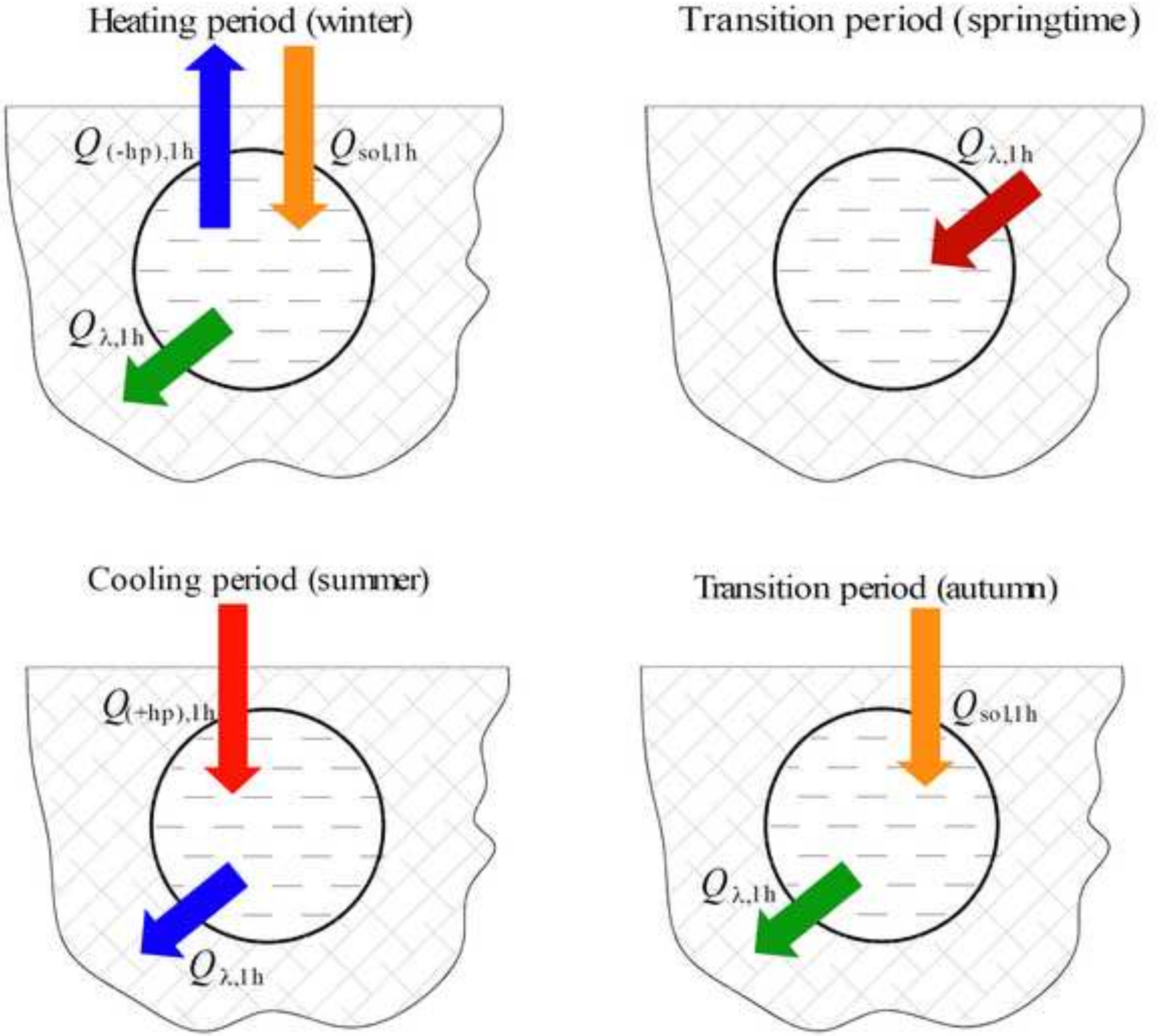

Heating period (winter)
$Q_{(-hp),1h}$
$Q_{sol,1h}$
$Q_{\lambda,1h}$
Transition period (springtime)
$Q_{\lambda,1h}$
Cooling period (summer)
$Q_{(+hp),1h}$
$Q_{\lambda,1h}$
Transition period (autumn)
$Q_{sol,1h}$
$Q_{\lambda,1h}$

Figure_3

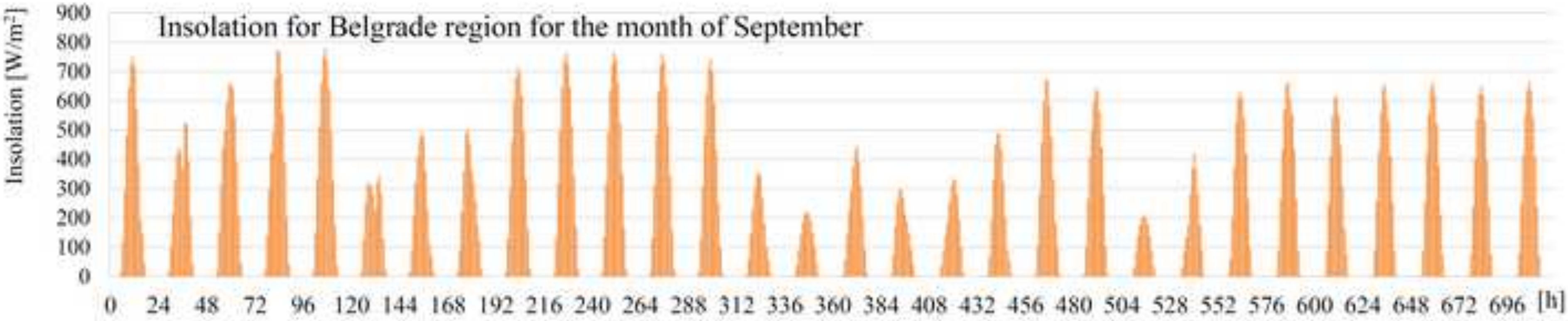

Insolation for Belgrade region for the month of September
Insolation [W/m²]
900
800
700
600
500
400
300
200
100
0
0 24 48 72 96 120 144 168 192 216 240 264 288 312 336 360 384 408 432 456 480 504 528 552 576 600 624 648 672 696
[h]

Figure_4

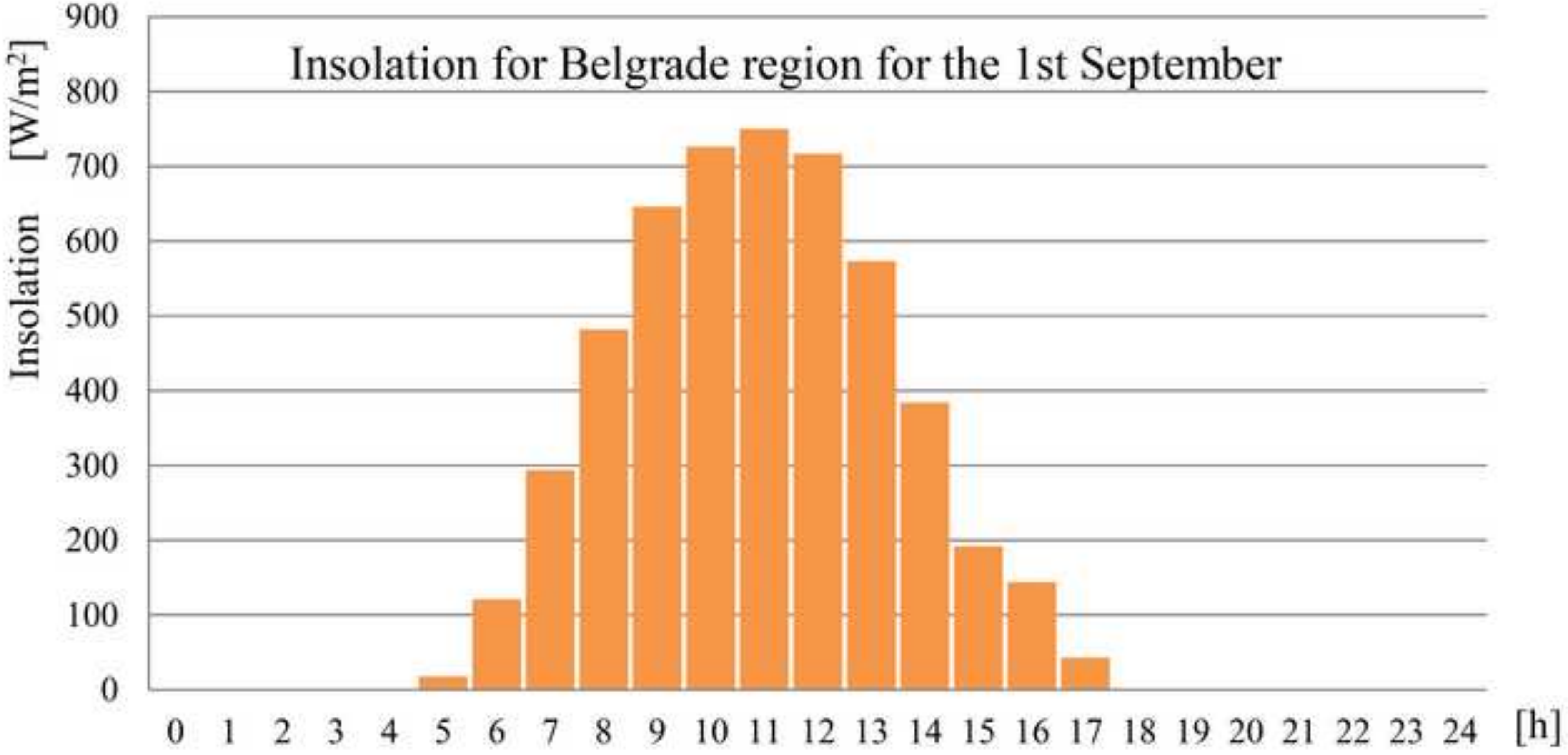
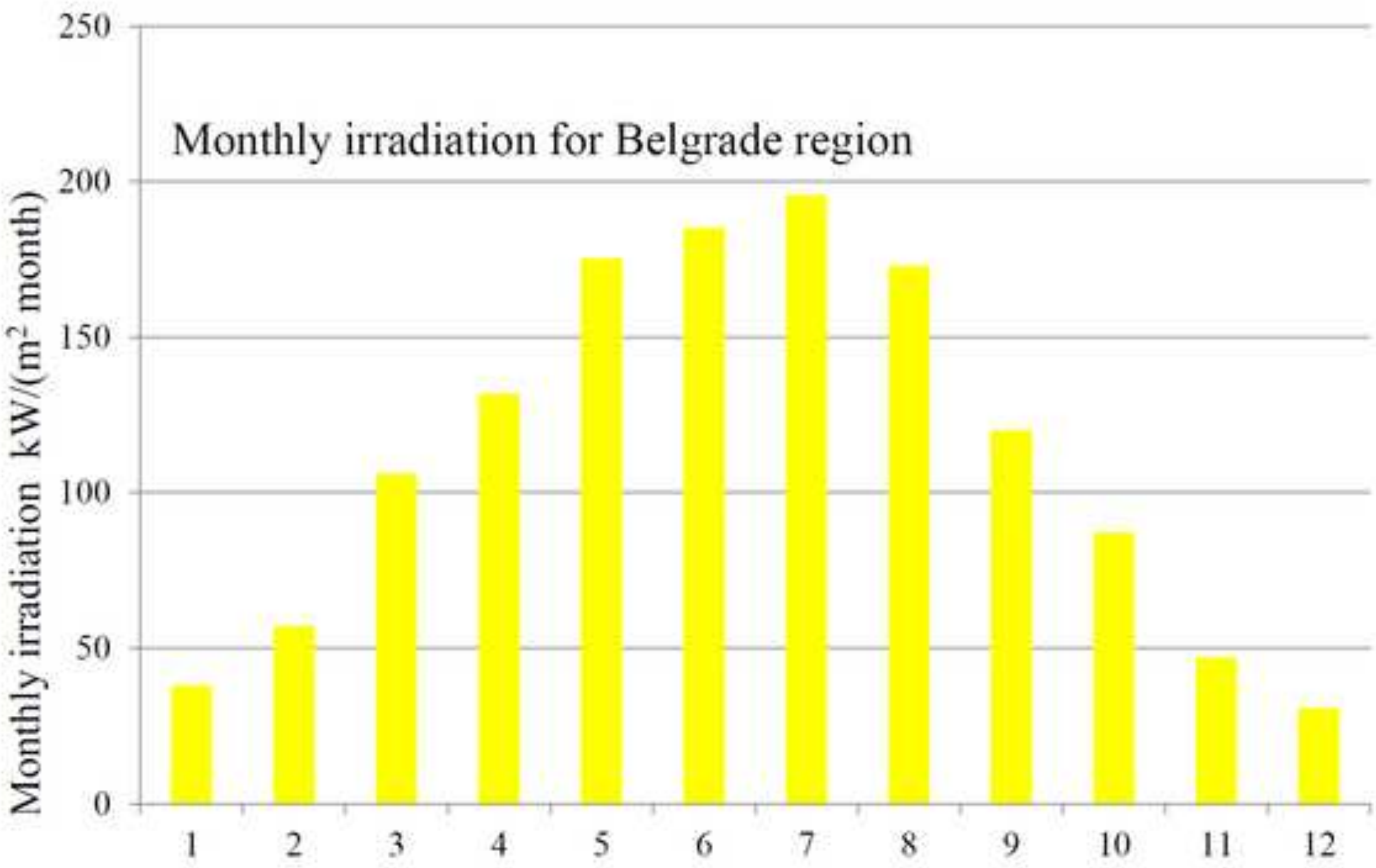

Insolation for Belgrade region for the 1st September
Insolation [W/m^2]
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
[h]

Figure_5


Monthly irradiation for Belgrade region
Monthly irradiation kW/(m² month)
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12

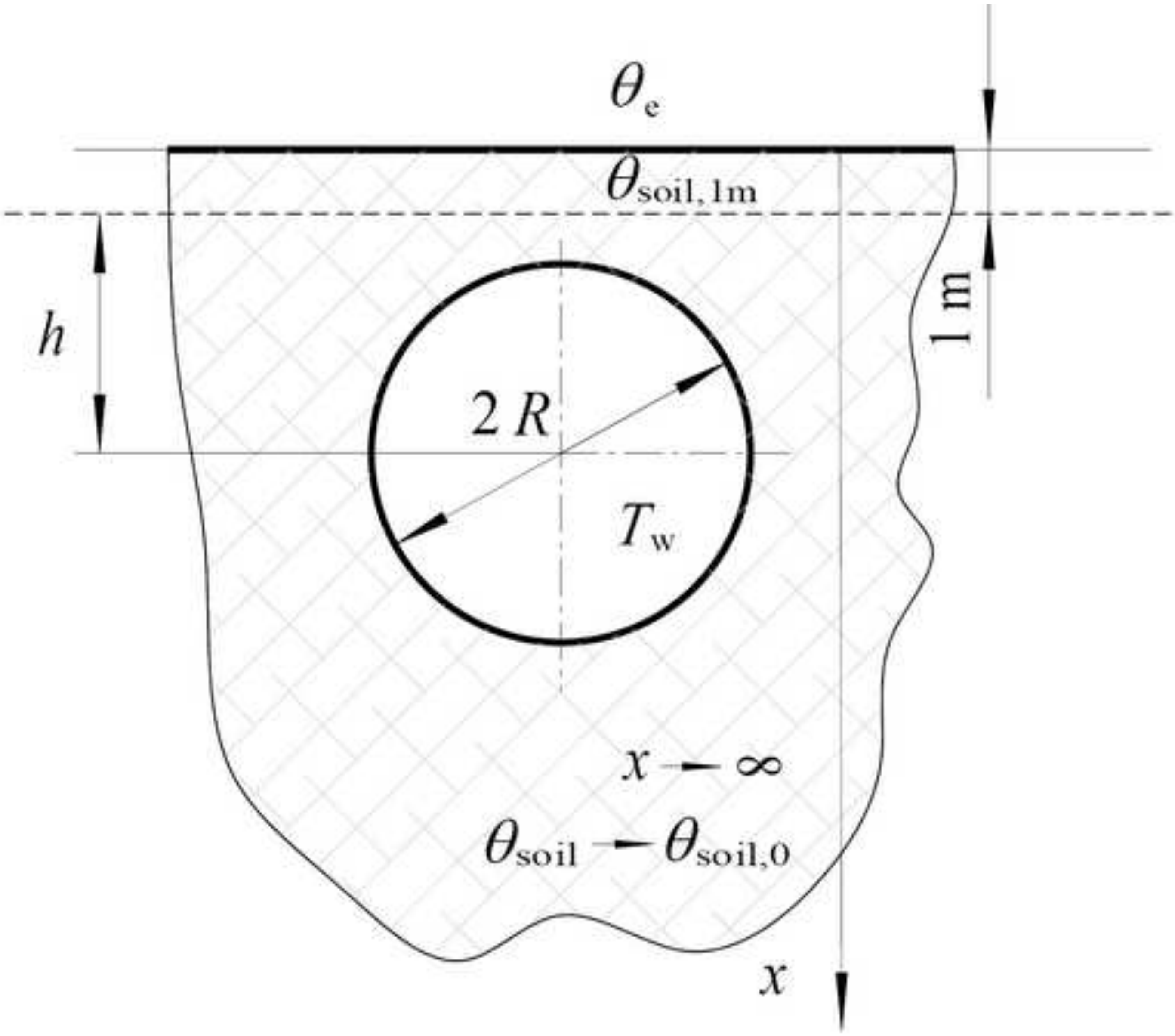

θ_e
$\theta_{soil,1m}$
1 m
h
2 R
T_w
$x \to \infty$
$\theta_{soil} \to \theta_{soil,0}$
x

Figure_7

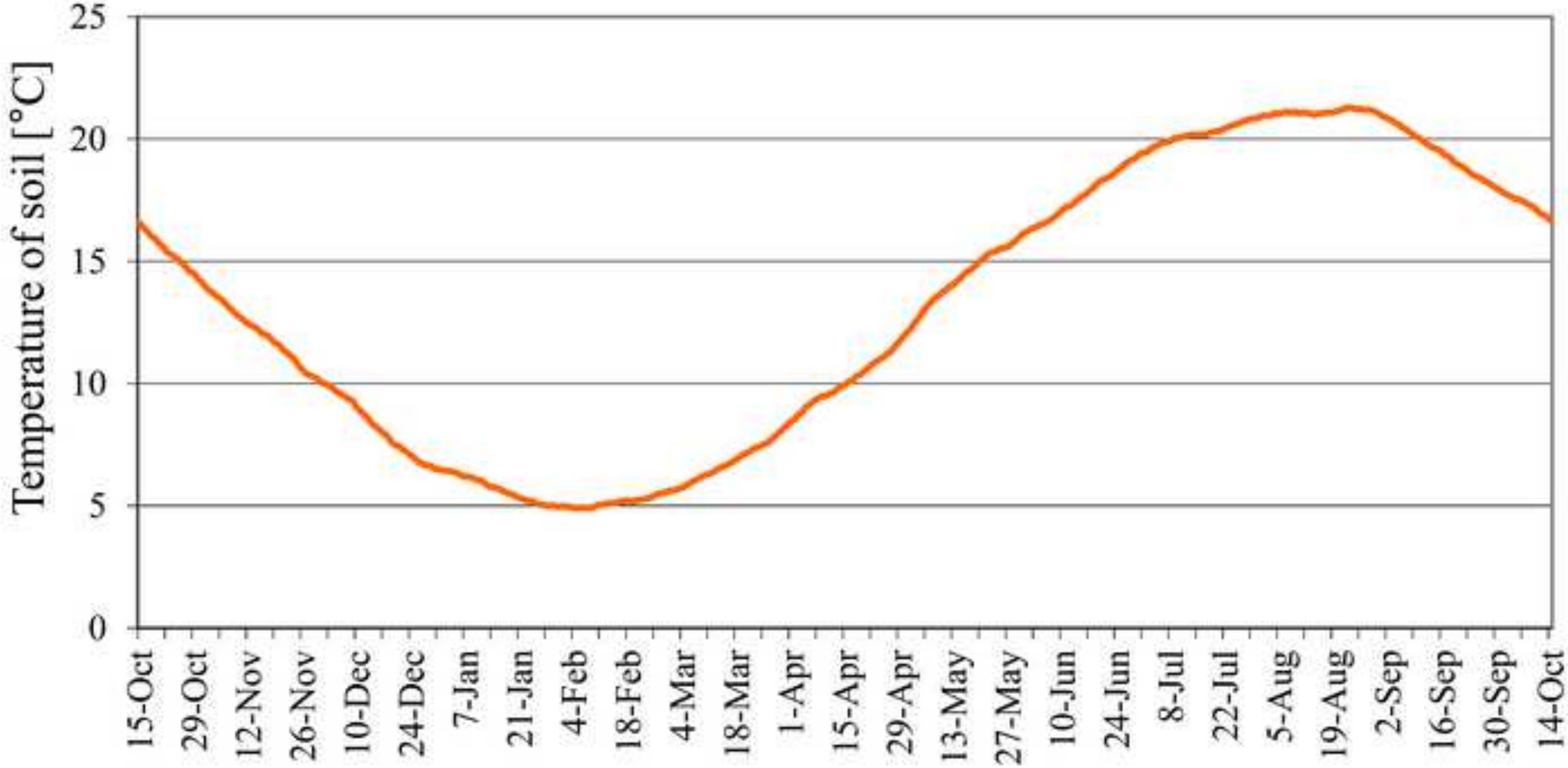

Temperature of soil [°C]
25
20
15
10
5
0
15-Oct
29-Oct
12-Nov
26-Nov
10-Dec
24-Dec
7-Jan
21-Jan
4-Feb
18-Feb
4-Mar
18-Mar
1-Apr
15-Apr
29-Apr
13-May
27-May
10-Jun
24-Jun
8-Jul
22-Jul
5-Aug
19-Aug
2-Sep
16-Sep
30-Sep
14-Oct

Figure_8

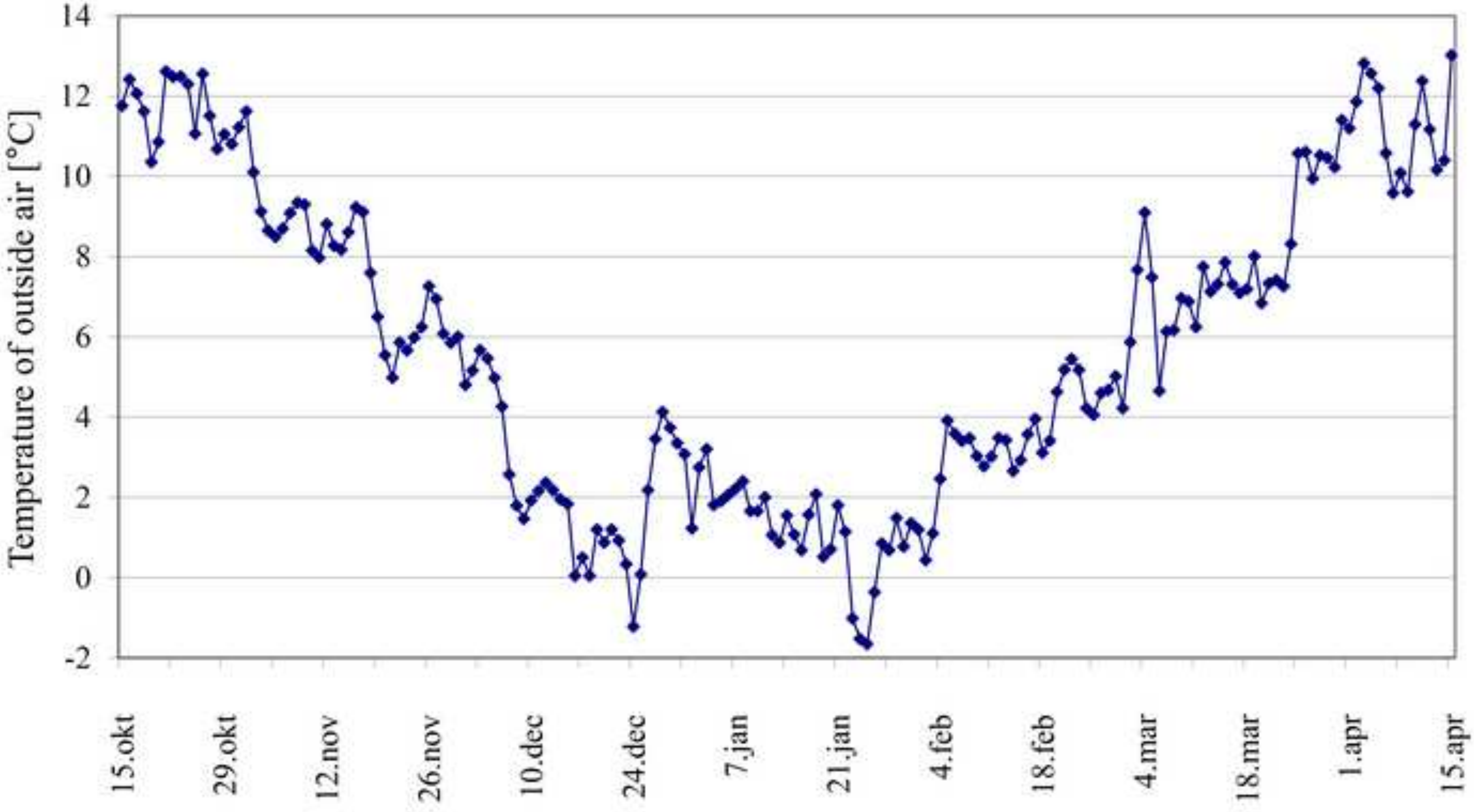

Temperature of outside air [°C]
14
12
10
8
6
4
2
0
-2
15.okt
29.okt
12.nov
26.nov
10.dec
24.dec
7.jan
21.jan
4.feb
18.feb
4.mar
18.mar
1.apr
15.apr

Figure_9

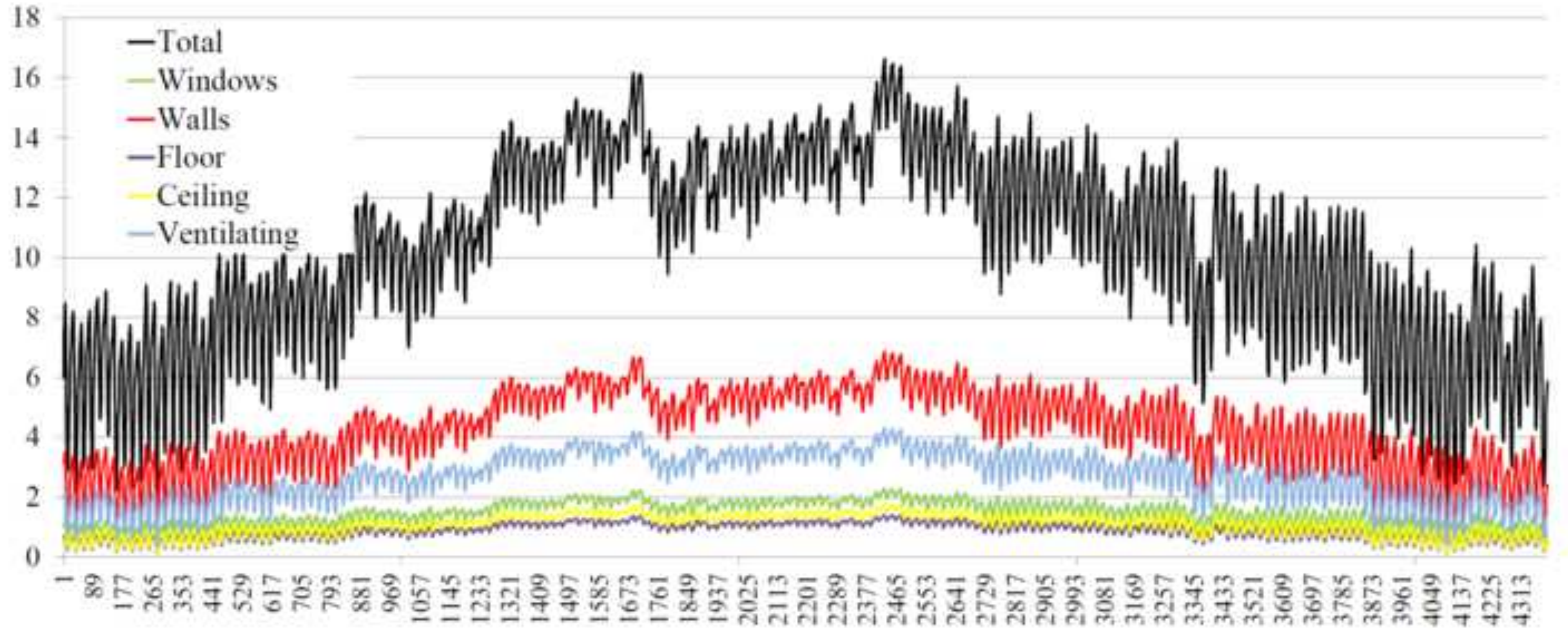
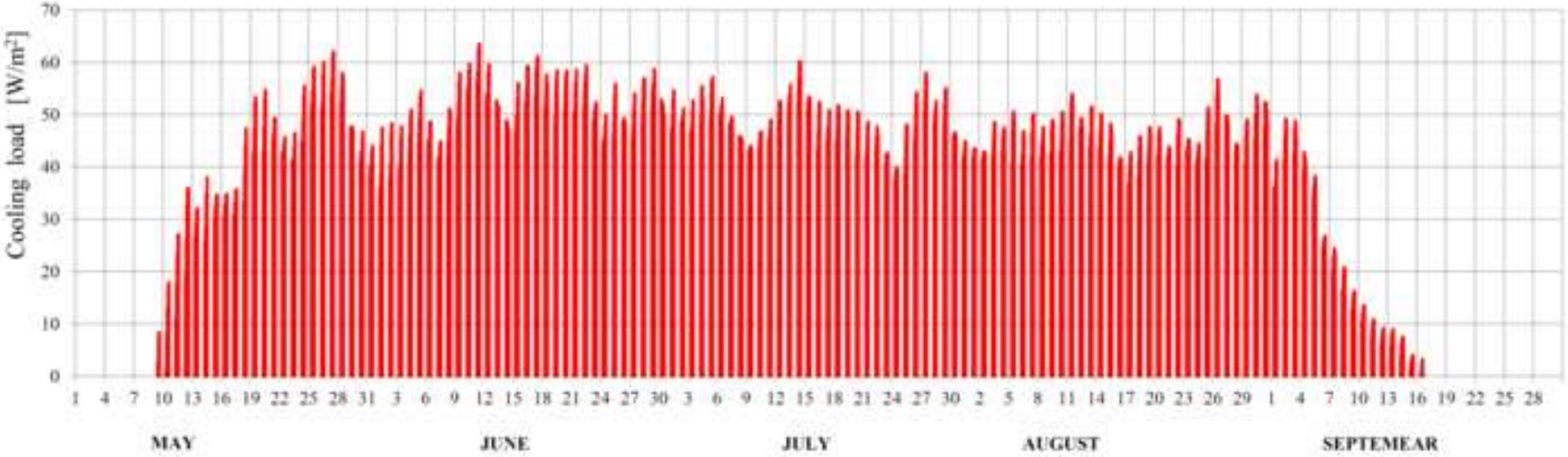

Total
Windows
Walls
Floor
Ceiling
Ventilating
18
16
14
12
10
8
6
4
2
0
1
89
177
265
353
441
529
617
705
793
881
969
1057
1145
1233
1321
1409
1497
1585
1673
1761
1849
1937
2025
2113
2201
2289
2377
2465
2553
2641
2729
2817
2905
2993
3081
3169
3257
3345
3433
3521
3609
3697
3785
3873
3961
4049
4137
4225
4313

Figure_10



Cooling load [W/m^2]
70
60
50
40
30
20
10
0
1 4 7 10 13 16 19 22 25 28 31 3 6 9 12 15 18 21 24 27 30 3 6 9 12 15 18 21 24 27 30 2 5 8 11 14 17 20 23 26 29 1 4 7 10 13 16 19 22 25 28
MAY
JUNE
JULY
AUGUST
SEPTEMEAR

Figure_11

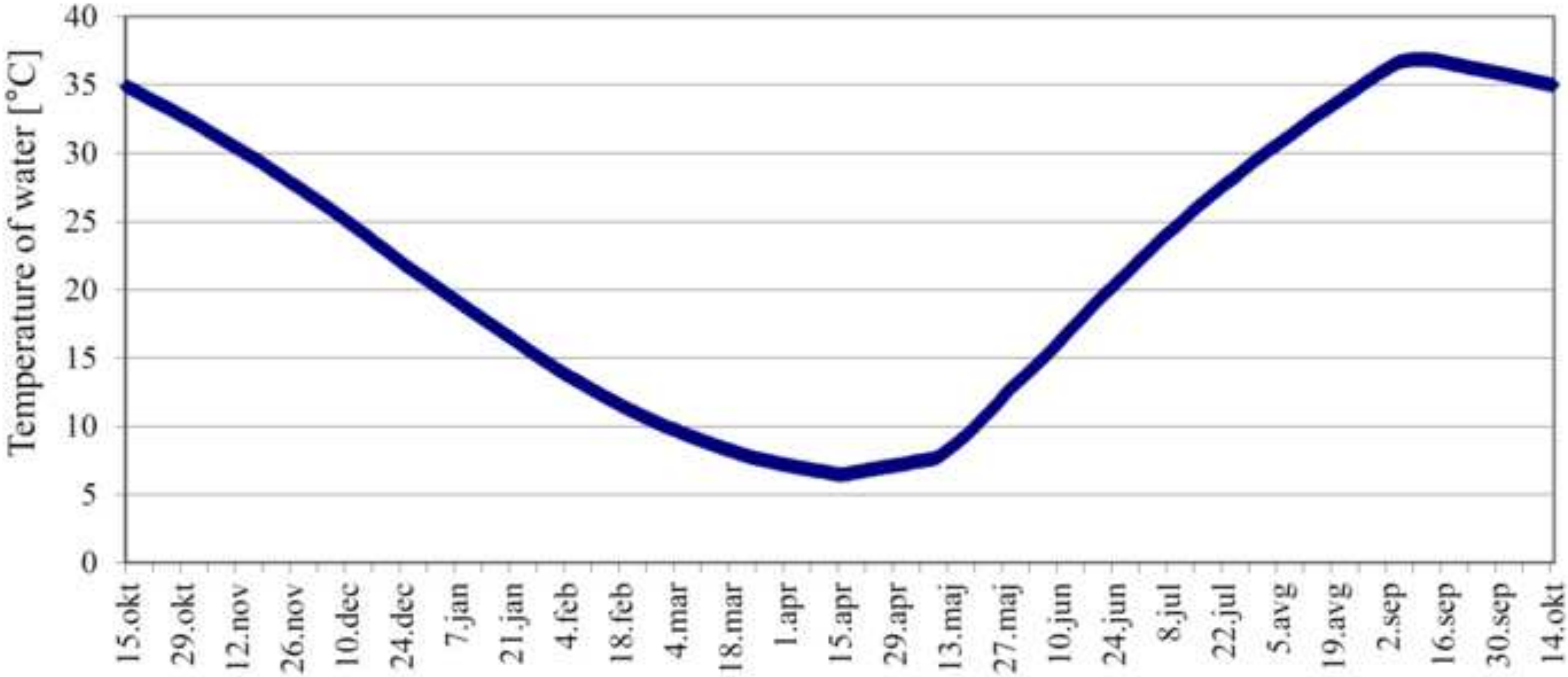
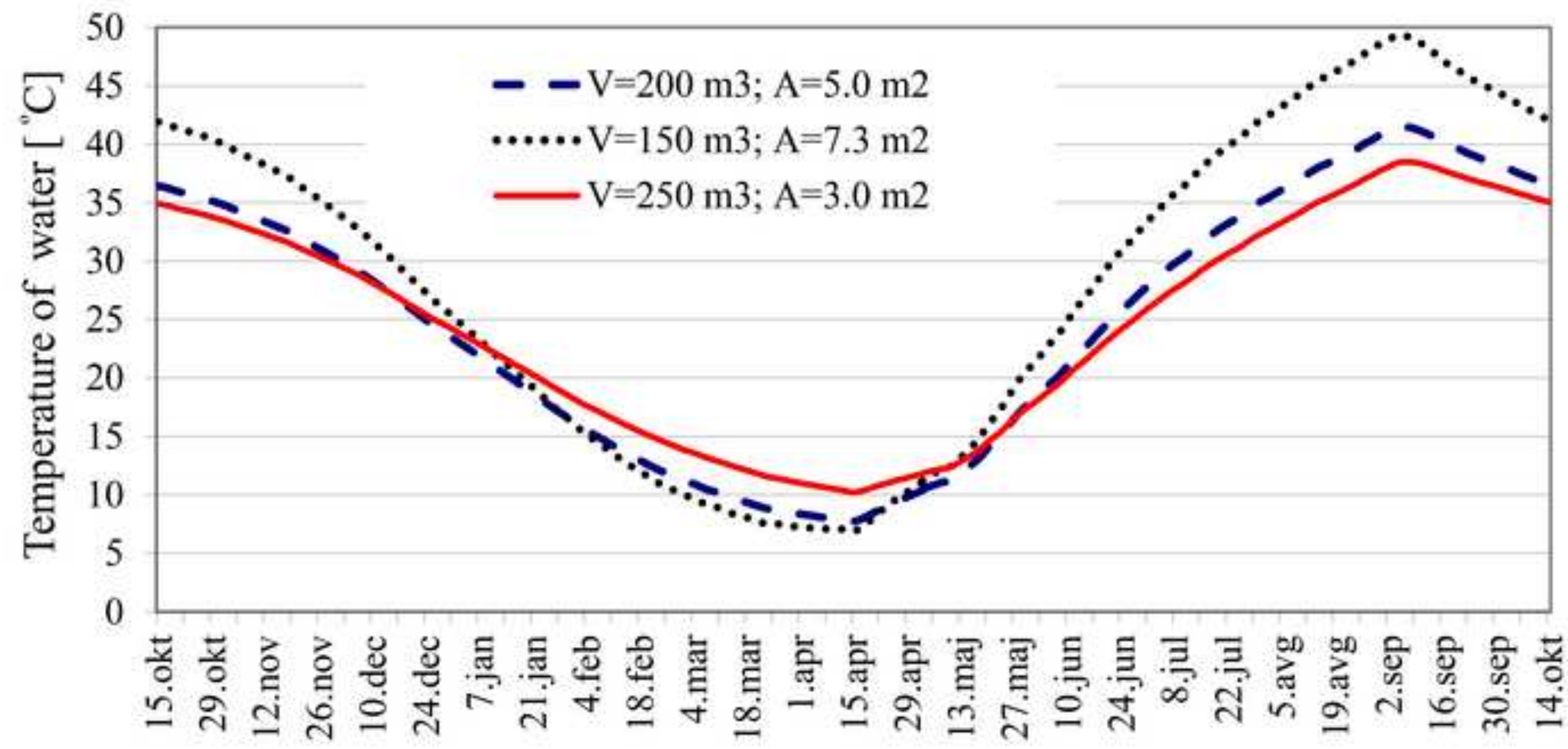

Temperature of water [°C]
0
5
10
15
20
25
30
35
40
15.okt
29.okt
12.nov
26.nov
10.dec
24.dec
7.jan
21.jan
4.feb
18.feb
4.mar
18.mar
1.apr
15.apr
29.apr
13.maj
27.maj
10.jun
24.jun
8.jul
22.jul
5.avg
19.avg
2.sep
16.sep
30.sep
14.okt

Figure_12



Temperature of water [°C]
50
45
40
35
30
25
20
15
10
5
0
V=200 m3; A=5.0 m2
V=150 m3; A=7.3 m2
V=250 m3; A=3.0 m2
15.okt
29.okt
12.nov
26.nov
10.dec
24.dec
7.jan
21.jan
4.feb
18.feb
4.mar
18.mar
1.apr
15.apr
29.apr
13.maj
27.maj
10.jun
24.jun
8.jul
22.jul
5.avg
19.avg
2.sep
16.sep
30.sep
14.okt

Figure_13

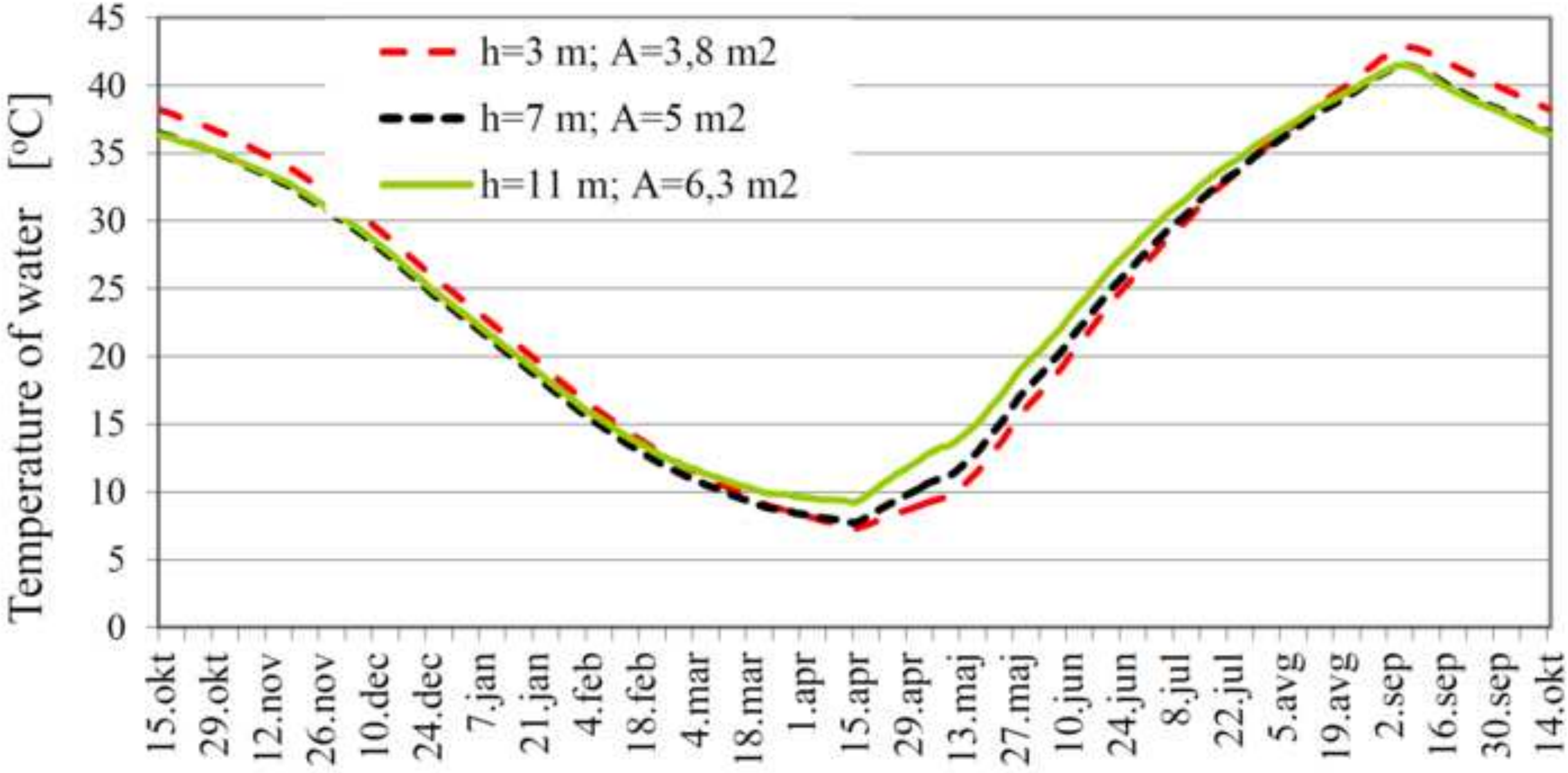
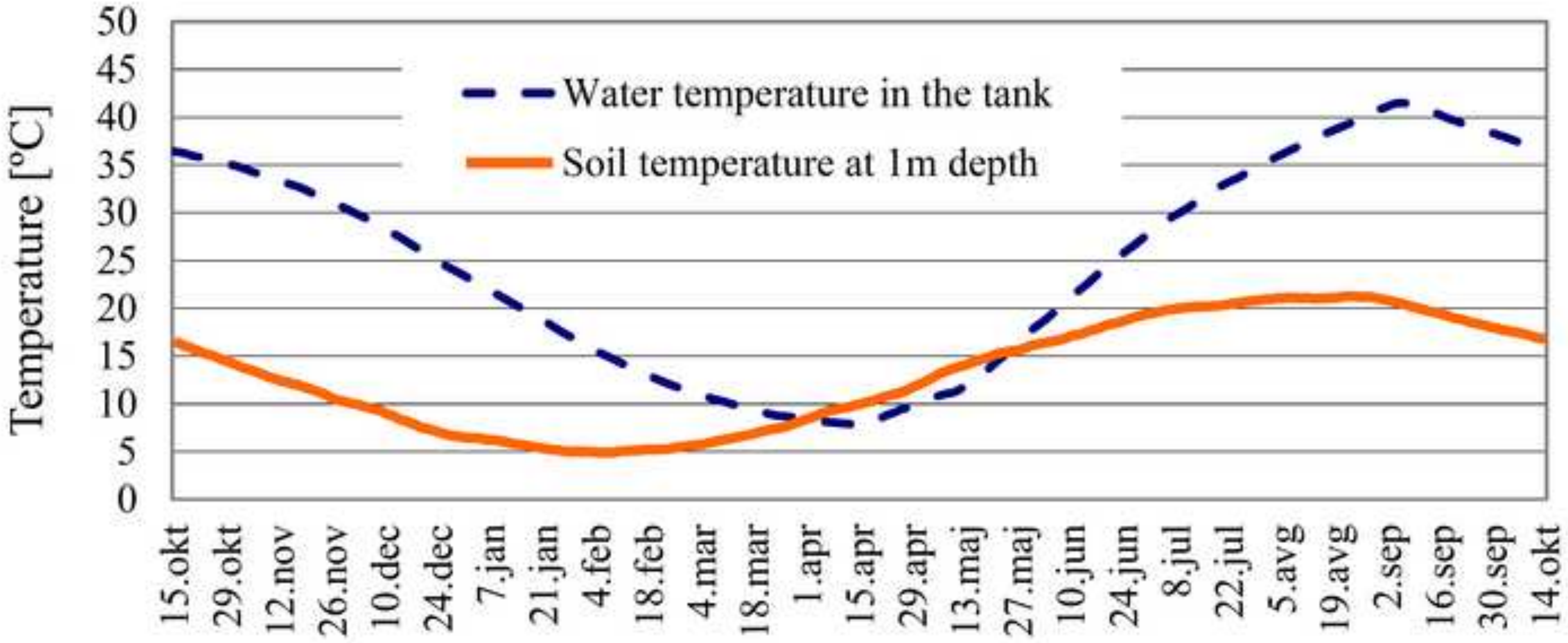

h=3 m; A=3,8 m2
h=7 m; A=5 m2
h=11 m; A=6,3 m2
Temperature of water [ºC]
45
40
35
30
25
20
15
10
5
0
15.okt
29.okt
12.nov
26.nov
10.dec
24.dec
7.jan
21.jan
4.feb
18.feb
4.mar
18.mar
1.apr
15.apr
29.apr
13.maj
27.maj
10.jun
24.jun
8.jul
22.jul
5.avg
19.avg
2.sep
16.sep
30.sep
14.okt

Figure_14


Water temperature in the tank
Soil temperature at 1m depth
Temperature [°C]
50
45
40
35
30
25
20
15
10
5
0
15.okt
29.okt
12.nov
26.nov
10.dec
24.dec
7.jan
21.jan
4.feb
18.feb
4.mar
18.mar
1.apr
15.apr
29.apr
13.maj
27.maj
10.jun
24.jun
8.jul
22.jul
5.avg
19.avg
2.sep
16.sep
30.sep
14.okt

Highlights

- *The new methodology of sizing a sustainable HVAC system with heat pump is presented*
- *System consist of heat pump, thermo solar collectors and underground water tank*
- *The methodology is based on successive and coupled energy balancing of elements*
- *The calculation result is the size thermal-solar collectors surface*
- *Checking the influence of parameters on the system's operation was performed*