COVERING OF HEATING LOAD OF OBJECT BY USING GROUND HEAT AS A RENEWABLE ENERGY SOURCE

by

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Rational use of energy, improving energy performance of buildings and use of renewable energy sources are the most important measures for reducing consumption of non-renewable primary energy (solid, liquid, and gaseous fuels), environmental protection and for the future sustainable development of mankind. In the total primary energy consumption great part is related to building industry, for heating spaces in which people stay and live. Renewable energy sources present natural resources and they are one of the alternatives that allow obtaining heat for heating buildings, and by that they provide a significant contribution to the energy balance of a country. This paper analyzes the participation of ground source as renewable energy sources, when the vertical (the probe in the ground) and horizontal (registry in the ground) heat exchangers are used for covering heating load of the building.

Key words: *renewable energy sources, ground, civil building, heating system, heat pump*

Introduction

Concern about energy and environmental occupied the world scientific community. These issues are the central point of many conferences, seminars and research papers for many years in the developed world. Namely, there is a constant dilemma: how to ensure a sufficient amount of energy necessary for the objects in which people live, and that this has no negative consequences on the environment and the natural balance of the planet.

The modern world tends to increasingly economic growth and increasing living standards, while he faces with the problem of shrinking the available energy resources, necessary to achieve that goal. Therefore, rational use and energy saving have become indispensable topics in most of the energy politics in the world. Global demand for energy grows under conditions of high and volatile prices, so the energy politics must take into account security in energy supply, competitiveness and sustainability.

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In seeking solutions to reduce energy consumption building sector has a major role, since buildings are one of the major energy consumers. Reducing energy consumption in building industry represents the greatest potential in energy economics, and thus makes a significant contribution to the energy balance of a country. One of the important measures to reduce non-renewable primary energy consumption for heating of buildings is the use of renewable energy sources (RES). Renewable energy policy is recent dated and it was approved the 1997 [1]. Since then, all the institutions of the European Union have made important steps towards positioning Europe with efficient resources as the primary objective of the European Union. The main elements of this strategy are consisted of promoting production of renewable energy and efficient energy use. In this sense, in the last few years much progress has been made.

The most important documents adopted by the European Union include: 2002/91/EC Directive (EPBD – The Energy Performance of Buildings Directive) [2], 2010/10/EU Directive (EPBD recast – The Energy Performance of Buildings Directive recast) [3] and the Renewable Energy Directive-Directive 2009/28/EC [4].

The aim of the Renewable Energy Directive 2009/28/EC is to increase the use of renewable energy in Europe. This directive obligates member states within the European Union through the use of renewable energy in the sectors of electricity, heating and cooling as well as in the transport sector, ensuring that by 2020 the renewable energy makes at least 20% of total energy consumption in the European Union. The Directive also predicts that up to 2020 the use of renewable energy in transport (biofuels, electricity and hydrogen produced from renewable sources) will make at least 10% of the total fuel consumption in the European Union.

In 2008, The European Union adopted an action plan for energy efficiency by 2020. The Action Plan was called "20-20-20", which means reducing energy consumption by 20%, increasing of renewable energy sources by 20% and reducing emissions of carbon dioxide and other greenhouse gases by 20%.

Republic of Serbia adopted the Energy Law in 2011 [5], which defines the National Action Plan, which sets targets for usage of renewable energy sources for at least 10 years. The plan specifically includes:

- the share of energy from renewable sources in gross final energy consumption,
- the share of renewable energy in total electricity consumption,
- the share of renewable energy in total energy consumption for heating and cooling, and
- measures and estimated financial resources for achieving the planned shares of energy from RES.

For reduction of the consumption of primary energy for heating buildings, Serbia adopted two important legislative acts in 2011 : Rule book of building energy efficiency [6] and Rule book on requirements, content and way of issuing of the certificates on building energy properties [7].

Before that, in terms of energy efficiency in Serbia other significant activities were conducted [8, 9].

RES, not only represent a real alternative for reducing non-renewable primary energy consumption and sustainable development of society, but also are the right choice when it comes to energy impact on the ecology, the environment, reducing carbon dioxide emissions and global warming of the planet.

"Accessibility of renewable energy sources, their availability in many areas of the world and eligibility for local use present concepts that are mutually interconnected. Both local and global level, just by filling all three requirements, renewable energy sources can provide a sustainable development concept of the world. Therefore, they enable compliance of four E (energy, environment, economy and efficiency) in the further development of mankind" [10].

This work analyzes the determination of possibility of ground source as RES for covering heating load of the building. Vertical (the probe in the ground) and horizontal (registry in the ground) heat exchangers are used to get heat from the ground.

Getting heat from the ground

"After all there are two categories of energy: solar energy and her related products (biomass, wind and water, which are practically inexhaustible benefits received from the sun) and other energies taken away from our Earth which unfortunately, have already been pretty much exhausted" [11].

A special group of RES make natural accumulators of solar energy: ground, water and outdoor air. The use of ground, water and outdoor air for re-getting heat is the indirect way of using solar energy. These sources are also called the regeneration heat sources, because after cooling, or after taking their heat away, they are re-heated by solar energy.

The ground as a regenerative source of heat is appropriate for heating buildings using heat pumps, because it already has a constant temperature at low depths, which is very important when using these types of sources. In winter months, at a depth of 1 m the temperature is 6-8 °C, while at a depth of 100 m, the temperature is up to +15 °C. The temperature fluctuation is lowest at depths greater than 6 m with the value ±1.5 °C, while the fluctuation is greatest near the surface and follows a change in temperature of the surrounding air. The heat from the ground is obtained by using horizontal and vertical heat exchangers.

Ground probes

Vertical heat exchangers are series of probes installed in boreholes at the depths of 50 to 150 m, usually at a depth of 100 m [12-15]. The pipes in boreholes are in the form of U or UU. The pipes are made of high quality polyethylene. The heat transfer that flows through them is a mixture of ethylene-glycol-water. After placing the probe, material that provides better contact between the pipe and ground is injected into the area around the pipes. Thus, 90% of the required heat energy comes from the ground in the systems with a probe, and only 10% from the Sun and the surrounding air.

The system with vertical heat exchangers is more expensive, but it is more efficient because of higher and constant temperature in deeper parts of the ground, and it is used to cover the higher heat loads. Heat output of this system depends on the composition of the ground and ranges 25-80 W/m (bad ground 25 W/m, medium ground 50 W/m, very good ground 80 W/m) [14, 16]. The exact values are available on site, depending on the geological and hydrological conditions. The system is ideal for small available space around the building, because it requires small workspace for the drilling equipment.

Ground collectors

Horizontal heat exchangers include piping system, placed into the ground at a depth of 1 to 2 m, usually at a depth of 1.5 m [12-15]. Since the pipes are near the surface, in order to avoid freezing of the heat carrier, the mixture of ethylene-glycol-water flows through the pipes. Pipe systems are made of high quality and environmentally harmless polyethylene. The heat effect of the system is from 10 W/m^2 to 40 W/m^2 [12, 14]. The smaller specific loss of heat results in the smaller area of the garden. At a depth of 1 m, 90% of the heat comes from the surrounding air and the Sun, and the heat generated from the ground is only 10%.

The mixture in the both systems operates in a closed circle, which means that it circulates through the pipes and transfers energy to heat pumps. It raises the energy to a higher temperature level, usable for house heating installation. The type of the ground affects the efficiency of both systems. The wet ground is preferred, while the sand should be avoided.

According to [12], and depending on the properties of the ground, the following table of specific heat effect of collectors in the ground is given.

Table 1. The specific heat effect of ground collectors

Properties of the ground	q [Wm^{-2}]
Sandy, dry	10
Sandy, wet	15-20
Clayey, dry	20-25
Clayey, wet	25-30
Clayey, saturated with water	35-40

Selection of the heating system

Economic justification of heating systems with renewable energy sources directly depends on their correct selection, which is determined by a number of factors for any specific case. Regardless of all the conditions in which the chosen systems are used, the basic factor of choice is economic, *i. e.* initial investment, maintenance costs and exploitation costs. Only a properly chosen heating system can provide economic justification of using RES for heating buildings.

Defining the most appropriate system of heating with RES implies finding the optimal alignment of energy efficiencies of its subsystems:
(1) the primary part: RES – heat pump, and
(2) a secondary part: internal heating installation,

In that defining we should include conditions to increase energy efficiency of one system part does not significantly reduce the energy efficiency of the second one.

When it comes to secondary part – internal heating installation, it is desirable that the heat pump condenser gets as much inlet water temperature to the inside installation, in order to perform the classical high-temperature heating installation. To achieve this, condensation temperatures in the heat pump cycle would also have to be high, which would suit both the high pressure of condensation.

High pressure condensation of heat pumps have two negative effects on the energy efficiency of the system, and thus on the economic feasibility of using heat pump for heating . First, for high pressure of condensation, higher invested work and higher consumption of electricity is necessary to activate the heat pump compressor, which reduces the energy efficiency of the system. Second, for the same heat pump capacity volume, flows of fluid in heat pumps are increased, and as a result we get more robust and expensive heat pump investment, which reduces the efficiency of the system. It is considered as optimal solution that heat pump, for the home heating system, produce initial water temperature at 40 °C [17, 18].

For example, by adopting temperature regime of low temperature heating system 40/30 °C, the condensation and evaporations temperatures are defined according to literature recommendations and heating coefficient of heat pump depends on them. Covering the thermal load of the building by vertical and horizontal heat exchangers in the ground also depends on them.

Participation of ground in covering heating load of object

Ground probes

Starting from expression which defines that heat pump covers 100% heating load of object:

$$Q = Q_{\mathrm{HP}} \tag{1}$$

Starting from the expression for the heat load of the heat pump:

$$Q_{\mathrm{HP}} = Q_{\mathrm{RES}} + E_{\mathrm{HP}} \tag{2}$$

and from the expression which defines the heating coefficient:

$$COP = \frac{Q_{\mathrm{HP}}}{E_{\mathrm{HP}}} \tag{3}$$

expression (2) can be expressed as:

$$Q_{HP} = Q_{RES} + \frac{Q_{HP}}{COP} \tag{4}$$

and after some rearrangements, we get the following expression, which defines the amount of heat obtained from the RES:

$$Q_{\mathrm{RES}} = Q_{\mathrm{HP}} \frac{COP - 1}{COP} \tag{5}$$

Participation of heat pump in covering of heat load is defined by the following expression:

$$Q_{\mathrm{HP}} = f_{\mathrm{HP}}\, Q \tag{6}$$

according to that expression (5) could be changed by formula:

$$Q_{\mathrm{RES}} = f_{\mathrm{HP}}\, Q \frac{COP - 1}{COP} \tag{7}$$

In case when ground is a heat source and when the probes are used for heat obtaining from the ground, it stands:

$$Q_{\mathrm{RES}} = Q_{\mathrm{GP}} \tag{8}$$

and also

$$Q_{\mathrm{GP}} = L_{\mathrm{GP}}\, q_{\mathrm{GP}} \cdot 10^{-3} \tag{9}$$

that is why according to eqs. (7) and (9) total length of a probe (probes) is defined by the following expression:

$$L_{\mathrm{GP}} = \frac{f_{\mathrm{HP}}\, Q}{q_{\mathrm{GP}}} \frac{COP - 1}{COP} \cdot 10^{3} \tag{10}$$

When heating load is defined by heating area A [m^2] and by specific heating load of the object q [Wm^{-2}]:

$$Q = qA \cdot 10^{-3} \tag{11}$$

eq. (10) could be written in such form:

$$L_{\mathrm{GP}} = \frac{f_{\mathrm{HP}} q A}{q_{\mathrm{GP}}} \frac{COP - 1}{COP} \tag{12}$$

For heat pump participation coefficient in covering of object heating load the following expression stands:

$$f_{\mathrm{HP}} \leq 1 \tag{13}$$

When

$$f_{\mathrm{HP}} = 1 \tag{14}$$

it means that heat pump covers 100% object heating load, *i. e.* it works in monovalent regime.

For

$$f_{\mathrm{HP}} < 1 \tag{15}$$

heat pump covers part of heating load and it works in bivalent (less suitable) regime with conventional boiler.

Heat pump participation coefficient in covering heating load of object f_{HP} depends on object heat load, *i. e.* on possibility of investement in the probes in the ground and of available free space for soil probes installation.

Specific heat performance of a probe in the soil depends on soil composition and it is determined by soil composition examination at the location of ground installation.

Starting from the expression for heat pump heating coefficient determination

$$COP = \eta_{\mathrm{HP}} \frac{T_c}{T_c - T_e} \tag{16}$$

value of this parameter depends on heat pump efficiency degree, η_{HP} and condensation temperature T_{c} [K] and evaporation temperature T_{e} [K] of the working cycle. Condensation temperature is defined according to temperature regime of low temperature heating installation (40/30, 40/35, 35/30 °C), with the limit that incoming water temperature to the house installation is restrained up to 40 °C. Evaporation temperature is determined according to water temperature in a closed cycle of the probe, *i. e.* according to water temperature at the outlet of the evaporator.

For adopted values of heat pump heating coefficient $COP = 4$ (they are achieved by the probes in the ground) L and specific heat load of the ground probe $q_{\mathrm{GP}} = 50$ W/M, eq. (12) finally becomes:

$$L_{\mathrm{GP}} = 0.015 f_{\mathrm{HP}} q A \tag{17}$$

According to expression (17), at figs. 1, 2, and 3 diagrams of the total needed length of a probe/probes are given according to specific heat load and object heating area, and also according to heat pump participation coefficient in object heat load cover $f_{\mathrm{HP}} = 1$, 0,75, and 0,50.

According to expression (7), specific heat load of RES in covering of specific heating load is determined by following equation:

$$q_{\mathrm{RES}} = f_{\mathrm{HP}} q A \frac{COP - 1}{COP} \tag{18}$$

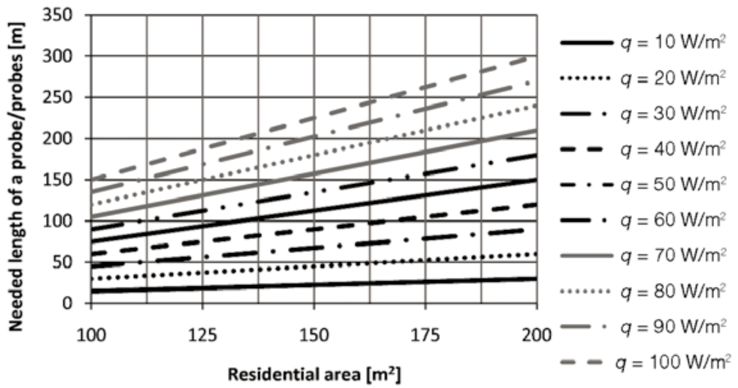

Figure 1. Needed length of a probe/probes for q_{GP} = 50 W/m and f_{HP} = 1.0

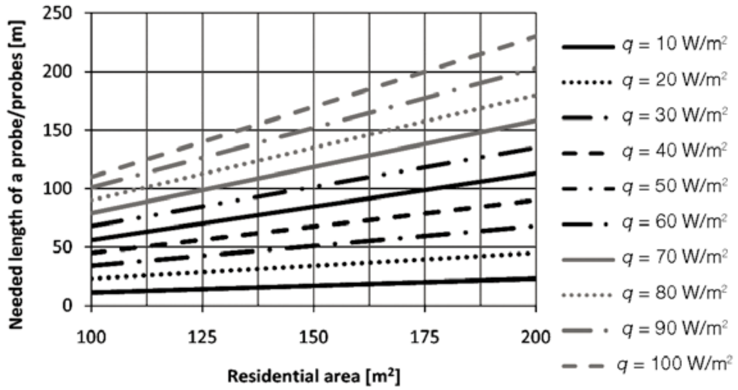

Figure 2. Needed length of a probe/probes for q_{GP} = 50 W/m and f_{HP} = 0.75

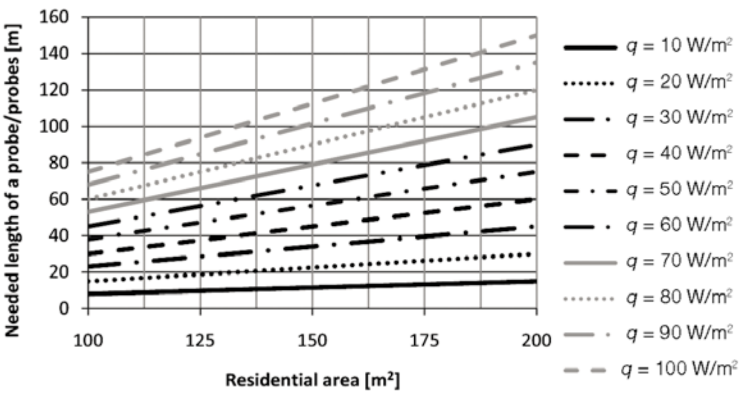

Figure 3. Needed length of a probe/probes for q_{GP} = 50 W/m and f_{HP} = 0.50

At fig. 4 the chart of specific ground participation is shown (with the ground probes), q_{GP} [Wm^{-2}] of object area in covering of heating load.

Registers in the ground

Comparing the probes in the ground, expression (9) becomes:

$$Q_{GR} = A_{GR}\, q_{GR} \cdot 10^{-3} \tag{19}$$

and expression (12) becomes:

$$A_{GR} = \frac{f_{HP} q A}{q_{GR}} \frac{COP - 1}{COP} \tag{20}$$

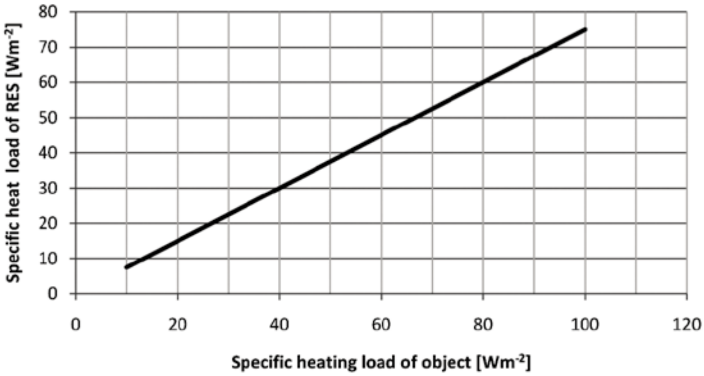

Figure 4. Ground participation (probes in the ground) in covering of heating load for f_{HP} = 1 and COP = 4

Because of the lower ground temperature at the depth of register installation (1-2 m), comparing the probes in the ground (50-150 m), lower water temperatures are achieved in the closed circle of the registers in the ground, and by that way lower heat pump heating coefficients. Considering, that at the depth of pipe register installation, ground with the is mostly regenerated by the outer air heating and Sun, on HP heating coefficient substantial influence have outer climatic conditions. In concrete cases, by examination of soil composition and ground temperature heating pump heating coefficient is determined and also specific system heating performance with registers in the ground [19].

For adopted values of heat pump heating coefficients, COP = 3.5 [14] for specific heat performance of the registers in the ground, q_{GR} = 25 W/m^2, expression (20) finaly becomes:

$$A_{GR} = 0.03\, f_{TP}\, q\, A \tag{21}$$

According to expression (21), at figs. 5, 6, and 7 are given charts of total needed area of the registers in the ground, and depending on specific heat load and residential heating area and heat pump coefficient of performance in covering of heating load of object, f_{HP} = 1, 0.75 and 0.50.

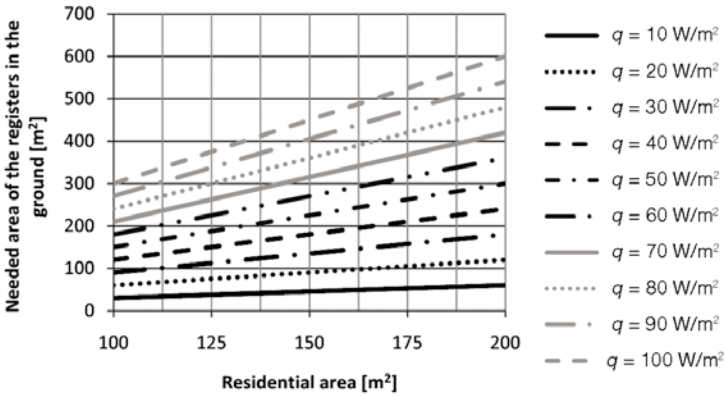

Figure 5. Needed area of registers in the ground for q_{GR} = 25 W/m^2 and f_{HP} = 1

At fig. 8 the chart of specific participation of ground is presented (with the registers in the ground), q_{GR} [Wm^{-2}] in covering of heating load of object according to expression (18).

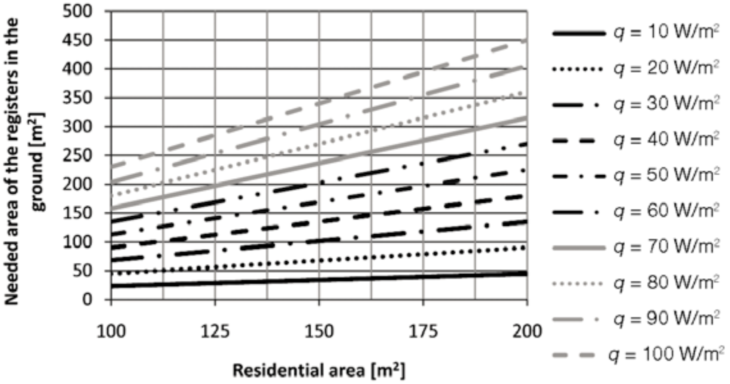

Figure 6. Needed area of registers in the ground for q_{GR} = 25 W/m^2 and f_{HP} = 0.75

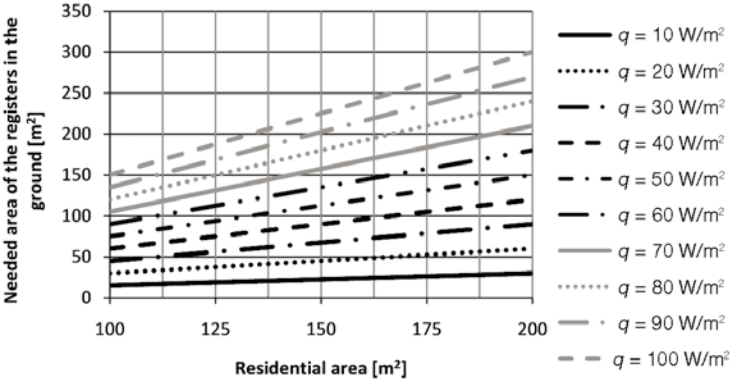

Figure 7. Needed area of registers in the ground for q_{GR} = 25 W/m^2 and f_{HP} = 0.5

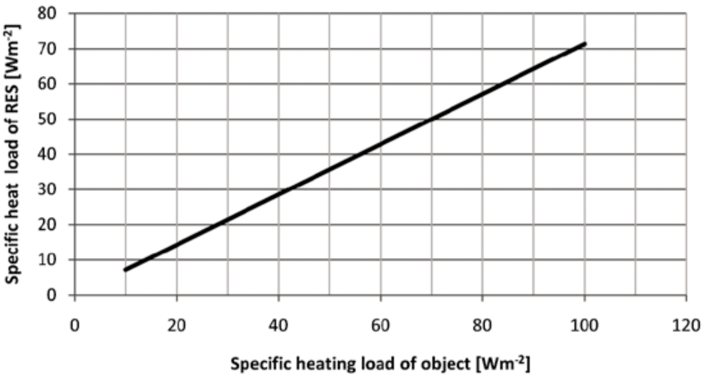

Figure 8. Ground participation (registers in the ground) in covering of heating load f_{HP} = 1 and *COP* = 3.5

Conclusions

Using of ground as a RES for object heat load covering depends on more factors. The most important are: (1) object heating heat load, (2) available area and soil composition around the object, (3) heating system selection and (4) economical validity of establishing system for obtaining heat from the ground.

There are demands for bigger available ground areas and HP functioning in bivalent (less favourable) working regime for incorporation of horizontal and vertical heat exchangers for objects with high heat load around the objects. The investments in the systems are higher, and energy efficiency of the system is less.

Ground energetic potential depend on the available area and soil composition around the object, as on the climate conditions of the area which should be determined by examination for every concrete case.

The system with vertical heat exchangers is more expensive, but is more efficient because of higher and constant temperature in deeper parts of the ground, and is used to cover the higher heat loads. The systems with horizontal heat exchangers are recommended for heating of small medium-sized objects, while larger buildings require more spacious area, as well as the composition of the ground that provides greater heat effects.

During the selection of heating system optimal compatibility of energy efficient subsystems should be defined: primary part (ground – heat pump) and secondary part (internal heating instalation). Working cycle of HP should be with as higher evaporation pressures as possible and as lower condensation presures as possible.

Distributing water temperature for house heating instalation (floor is the most optimal) should be up to 40 °C, and temperature regime of low-temperature heating instalation 40/30, 40/35, 35/30 °C. Lower distributing water temperatures are for the objects with less specific heating load.

Choice of heating system with ground as a RES depends on economic calculation of validity, which include investments in these systems and savings accomplished in primary energy consumption. The results of these calculations define participation of heating system with the ground as RES in covering heating load of object.

Nomenclature

A – area, [m^2]
COP – heating coefficient, [–]
E – electric power, [kW]
f_{HP} – coefficient of covering heating load by heat pump, [–]
L – length, [m]
Q – heating load, capacity, [kW]
q – specific heating load, covering heating load, [Wm^{-2}]
T_c – condenser temperature, [K]
T_e – evaporator temperature, [K]

Greek symbol

η_{HP} – efficiency coefficient of heat pump, [–]

Subscripts

E – electricity
G – ground
GP – probes in the ground
GR – registers in the ground
HP – heat pump

Acronyms

HP – heat pump
RES – renewable energy sources

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