Passive Residential Houses with the Accumulation Properties of Ground as a Heat Storage Medium

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Abstract. Solar radiation is the primary source of life energy on Earth. The irradiance of the upper atmosphere is about 1360 W/m^2, and it is estimated that about 1000 W/m^2 reaches the ground. Long-term storage of heat energy is related to the use of a suitable thermal energy carrier. It may be either artificial or natural water tank, or artificial gravel-water tank, or aquifer or soil. It is justified to store the generated energy in large heating systems due to the nature of solar thermal energy. Typically, in such a solution storage space is a large solar collector farm. The reason for this is the proportionally small unit profits, which only in the case of large number of units provides sufficient energy that can be accumulated. It should be noted that Poland, a country located in a temperate and less harsh climate such as Scandinavia and Canada, has a relatively high potential for solar revenue. In the last decade, it has caused mainly small and individual heating installations. However, much of the municipal and industrial economy continues to rely on energy from non-renewable resources. This is due not only to the lack of a high-efficiency alternative to non-renewable energy resources, but also to the thermal state of buildings throughout the country, where old buildings require thermo-modernization. This has the effect of both polluting the environment and the occurrence of smog, as well as pollutants in water and soil. This directly affects the occurrence of civilization diseases and other societal health problems. Therefore, the surplus of thermal clean energy that occurs during the spring and summer period should not only be used on a regular basis, but also stored for later winter use. The paper presents the concept of housing estate, which consists of 32 twin housing units. The solid character of buildings consistently refers to passive construction, and the materials meet the requirements for the passive buildings.

1. Introduction

A key issue determining the development of the energy sector worldwide and in Poland is the matter of efficient energy and environment management. Although the share of renewable energy has clearly improved over the last two decades, the energy needed to meet demands of mankind is still based in about 80% on non-renewable resources. It is estimated that with the projected increase in mining, documented reserves of fossil fuels will allow us to meet the needs for about 100 years [1]. Also the uncertain situation is in the commodity market, where, according to the International Energy Agency - IEA, energy prices are already at a minimal level compared to mining costs. Hence, the increase in mining costs due to the disappearance of fossils in readily accessible areas is expected. This is a sign of a precarious political situation and a further dependence of countries without energy resources from the mining trusts [2].

Another issue is that each unit of energy consumption is accompanied by extraction of toxic gases. It is both an environmental pollution (which results in civilization diseases), as well as the storage of greenhouse gases in the atmosphere, blocking possibility of earth heat radiation and formation of the greenhouse effect. This result is an increase of temperature, which in turn leads to irreversible climate changes - desertification of continents and melting of the arctic and Antarctic ice. That is why sustainable development of renewable energy technologies is essential. The important thing is also to reduce the demand for energy by using advanced and reliable technology in each brand of industry. It is estimated that for developed countries, the third part of the total energy produced is consumed by building industry. At least 65% of this value is used in a moderate climate zone for heating purposes [3].

Therefore, in recent years, not only economic but also ecological considerations are taken into account in the generation of energy. Hence, in the construction industry, the development of energy-saving technologies and materials is the foundation of passive, zero-energy and positive energy construction. The main sources of energy in these types of facilities are unconventional and renewable energy sources such as solar radiation, wind power, marine currents, geothermal waters, and biomass use. The share of renewable energy in overall energy generation is increasing steadily from year to year, resulting from the ever-increasing availability of such solutions [4].

2. Passive building structures

The Passive House is a building with extremely low energy requirements for interior heating ca 15 kWh/m^2/year. Thermal comfort is ensured by the passive heat sources i.e. inhabitants, and electrical appliances, and solar heat, as well as heat recovered from ventilation and heating of ventilation air. The building does not need an autonomous, active heating system [5]. The passive house, already at the early design stage, must meet the following criteria: adequate building shape, proper orientation of the building to the world's sides (including terrain), maximum glazing of the southern façade (high solar gain), adequate thermal insulation, mechanical combined heat recovery with auxiliary equipment, electricity generated from sunlight or wind power, hot water heated by sunlight, etc. In the case of zero energy or positive energy construction, we are dealing with the development of passive construction and the broad use of alternative energy sources [6].

Solar radiation is a source of energy with high technical potential. The sun has been seen for many years as a solid and clean source of energy. The intensity of the irradiated upper layers of the atmosphere is about 1360 W/m^2. About 30% is reflected from the Earth's atmosphere, and 47% is absorbed by the sea and oceans, and 23% is consumed in the hydrological circulation (evaporation, precipitation) [7].

On the basis of Meteorological Institute (IMGW) studies the zoning of solar energy resources in Poland is presented. The amount of sunlight in our country ranges from 950 to 1250 kWh/m^2 per year e.g. Zielona Gora [8,9]. The most privileged region (above 1,048 kWh/m^2 per year), as it is visible in Fig. 1, is the south-eastern part of the Lublin province [10]. On the contrary, in Poland the average level of sunshine throughout the year, i.e. the number of hours of sunshine (such parameter describes the weather conditions) is about 1600 hours/year. It is worth mentioning that 80% of the total solar radiation occurs in spring and summer (from early April to late September) [7].

3. Solar heating systems using long term energy storage

It is assumed that the large heating solar system is the system with an area of more than 500 m^2. Currently the largest heating solar installation, launched in December 2016 is located in Silkeborg, Denmark. It consists of 156,694 m^2 of solar collectors, which are able to produce annually approximately 80,000 MWh, which is 20% of the Silkeborg annual heat demand.

Solutions of this type are usually applied in three main configurations:

- Central Solar Heating Plant with Diurnal Storage (CSHPDS) – short term storage system,
- Central Solar Heating Plant with Seasonal Storage (CSHPSS) – long term storage system,
- installations without storage connected directly to the heating network (CSHPxS).

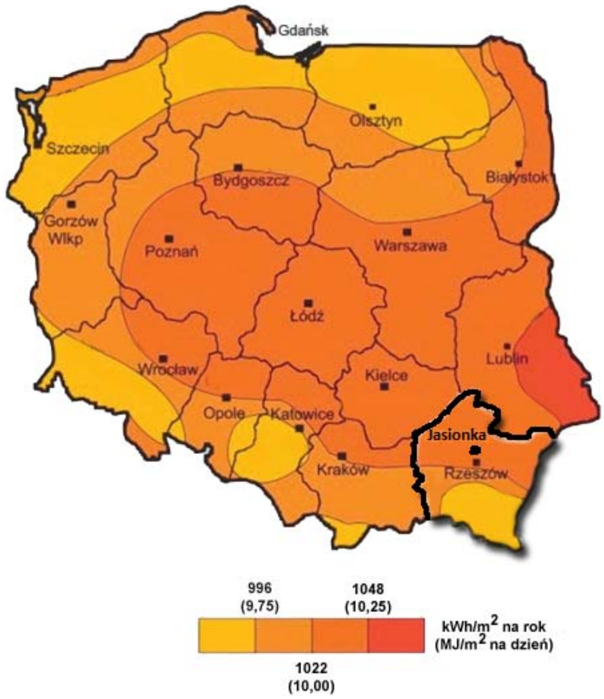

Figure 1. Zoning solar energy resources in Poland [10]

Long-term storage of heat energy associated with the use of appropriate carrier of thermal energy, it may be: artificial or natural water reservoir, artificial reservoir of gravel and water, the aquifer or soil [11]. The systems for energy storage in the soil are vertical heat exchangers transmitting the heat directly into the soil. Transportation of energy may be based on Field pipes (inner tube is coaxially in outer tube) or by a single elongated U-tube. Soil energy storage has a lower equivalent heat capacity of water compared to other storages amounting to approximately 0.2-0.3 m^3 per 1 m^3 of soil (e.g. gravel and water storage has 0.5-0.75 m^3) [7]. An example of such a solution is a housing estate in Okotoks, Alberta (Canada). These are the 52 housing facilities consisting of a residential area and the garages. Energy from solar radiation dispenses here in two ways:

- by 104 solar collectors located on residential buildings - hence the acquisition of heat required to heat the water - as individual use of solar energy,
- approximately 800 solar collectors (circa 25000 m^2) mounted on the roofs of garages - generating the thermal energy required for heating in the winter - as the team cooperation in generating thermal energy, as it is shown in Figure 2, [12].

The energy collected by the solar collectors is absorbed by the glycol, which transports the heat through the exchanger to the energy center of the community (EC - Energy Center), and then returns to the collector. There are 120 m^3 water storage tanks (STTS - Short Term Thermal Storage), which are used for short-term energy storage and also work as a buffer neutralizing the surplus of energy in the summer, as it is visible in Fig. 3. Long-term energy storage takes place by means of borehole energy storage (BTES – Borehole Thermal Energy Storage). The seasonal borehole thermal energy storage (BTES) is comprised of a grid 144 boreholes with single U-tube heat exchangers made of cross-linked polyethylene. It is configured to maintain the center of the storage at the highest temperature to maximize heating capacity. The outer edges are maintained at the lowest temperature to minimize heat losses. The boreholes are spaced radially (at 2.25 m), and form a system in a shape of an octagon having a diameter of 37 m and a height (depth) of 35 m, as it displays Fig. 4. The heat transport to BTES is via the heat exchanger, which transfers heat from the STTS. Propagation of thermal energy using a glycol is carried out radially from the center of BTES, until its edge (circumferential) where the glycol with a lower temperature is transported back to the heat exchanger connected to the STTS. During the heating season glycol flow is performed in the opposite direction - from the edge to the centre BTES.

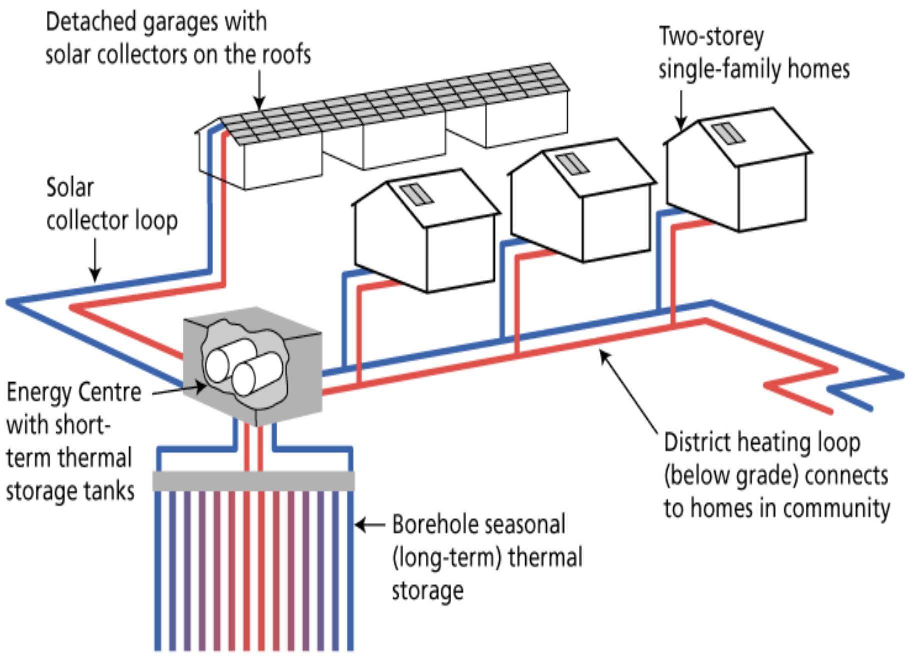

Figure 2. Diagram layout of the individual elements of the thermal energy acquisition [12]

Then the liquid gets heated by the heat exchanger to the STTS, which is connected via a separate line with the housing units. There, the heated air is spread throughout the central mechanical ventilation system. Fig. 5 presents the ventilation system.

It should be pointed out that the efficiency of the BTES, is variable and tends to increase. It is estimated its maximum level would be equal to 65%. This is due to the accumulation properties of the undisturbed soil, that being the carrier of thermal energy takes seasonal accumulation of the heat in the long term.

4. The concept of housing estate using the storage of solar energy

Based on the above a system of recovery and storage of solar energy as heat is developed with the concept of housing estate supplied energy for heating using ground heat storage. The location of the settlement is Jasionka town, located in the central part of the Sub-Carpathian province and having high solar energy resources [10]. Lithological profile of the selected area consists of homogeneous layers of Quaternary sand (at considered depth), so as both the distribution and redistribution of heat will take place here uniformly throughout the ground heat exchanger. Also, topography of the land (flat and wide area) gives the full access to solar radiation.

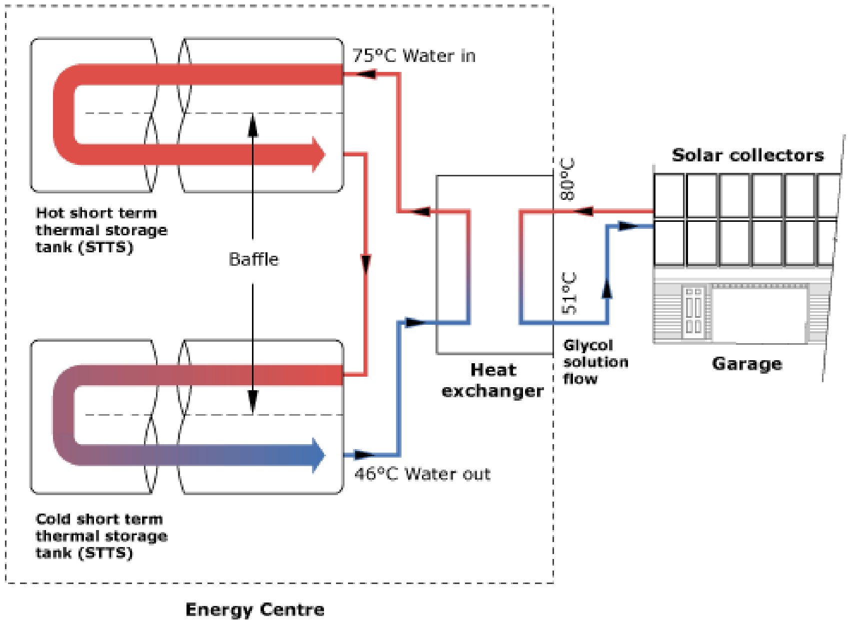

Figure 3. Short-term energy storage (STTS) and heat exchanger [12]

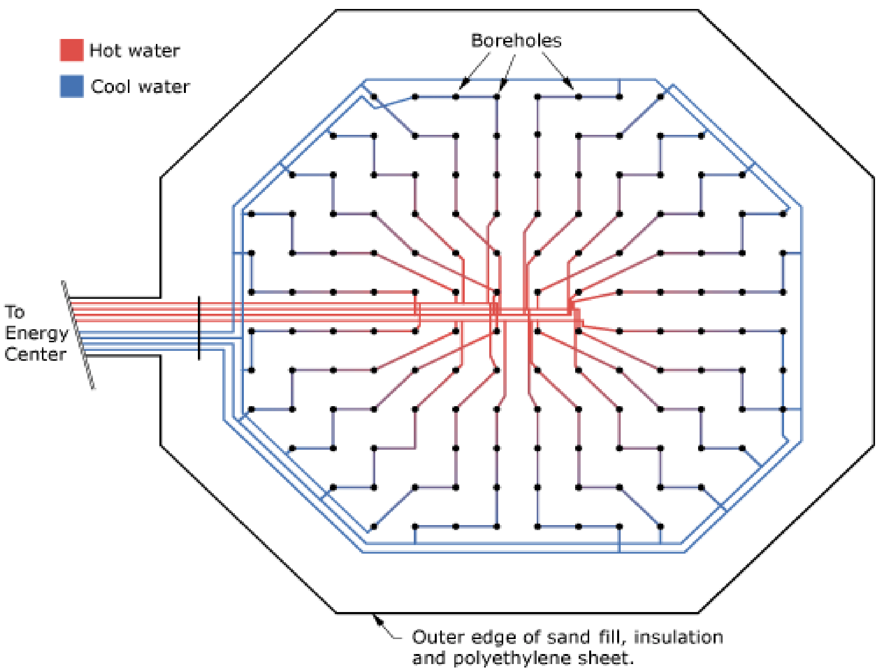

Figure 4. Heat exchanger of ground heat accumulator BTES [132]

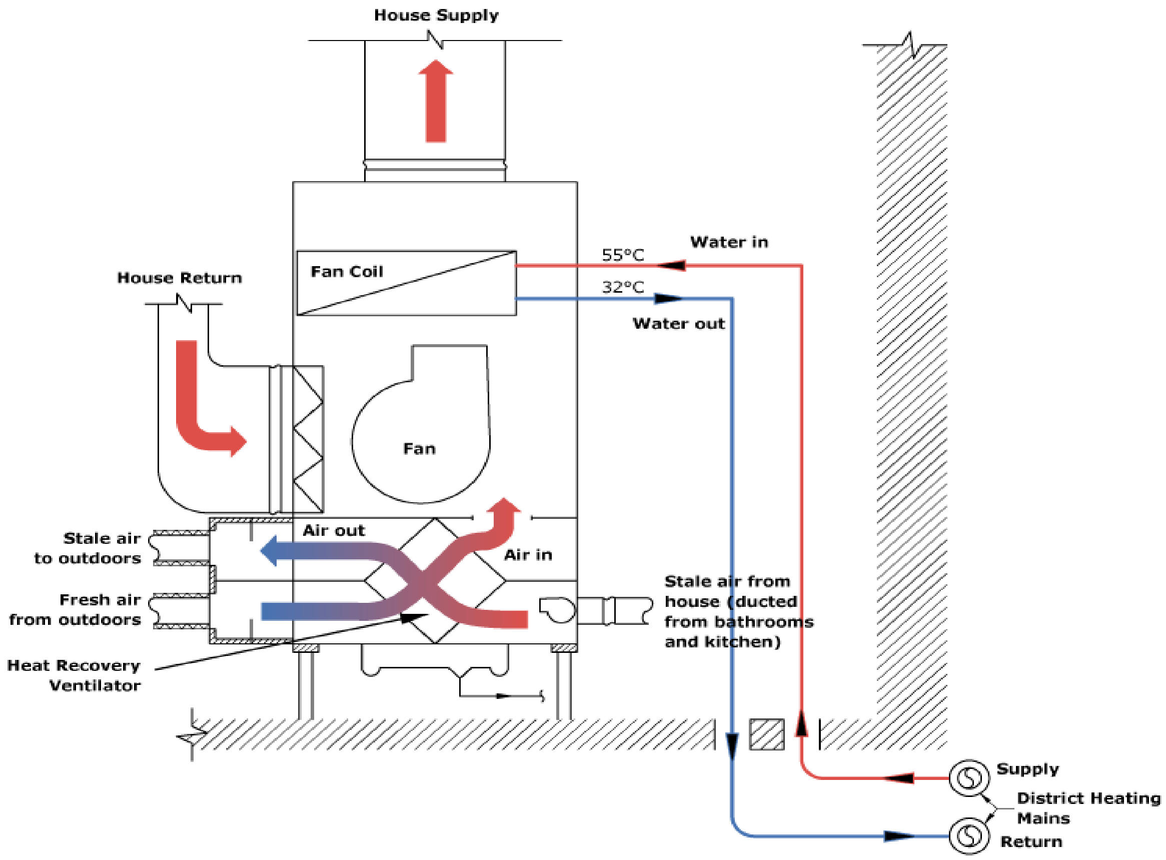

Figure 5. Central mechanical ventilation system with heat recovery ventilator [12]

The subject of this paper is a residential complex consisting of housing units in the form of 32 single-family dwellings. Solid character of the structures consistently refers to the basics of passive buildings. In order to eliminate as many thermal bridges as possible a continuous insulation should be applied and a range of such solutions is proposed. Moreover, underlining ecological character of family dwellings, they may be equipped with green roofs. Figure 6 presents such an example of housing estate.

The area of 82.0 m2 of roof surface is allocated to acquire solar energy. The area of 42.1 m2 is dedicated to flat type collectors gathering the energy for heating the community, while the area of 10.8 m2 is planned for vacuum-type collectors gathering the energy for individual targets i.e. hot water. The remaining area of 29.1 m2 is designed for the photovoltaic cells. Two kinds of solar collectors are applied. Vacuum devices have a higher efficiency in the autumn-winter season. The process will be followed by recovery of thermal energy for heating the ground heat accumulator and maintenance of flat collectors working for the community. In addition, to maximize the profits the whole set of collectors will use electro-hydraulic actuators, so as to automatically tune the best position relative to the sun.

Here are the remaining elements of the concept: the building of a temporary energy storage (temporary storage of thermal energy) and ground heat accumulator. Each of these objects is connected to the other (and to the single family dwellings) by a transmission line, which is especially prepared duct located below the frost penetration and protected by thermal insulation and provide continuous control and maintenance. The cooperation of individual components of the system i.e. a single housing unit transferring heat to the building temporarily and then to ground accumulator is done according to the scheme analogous to that presented in the previous section. Figure 7 presents diagram of such an installation.

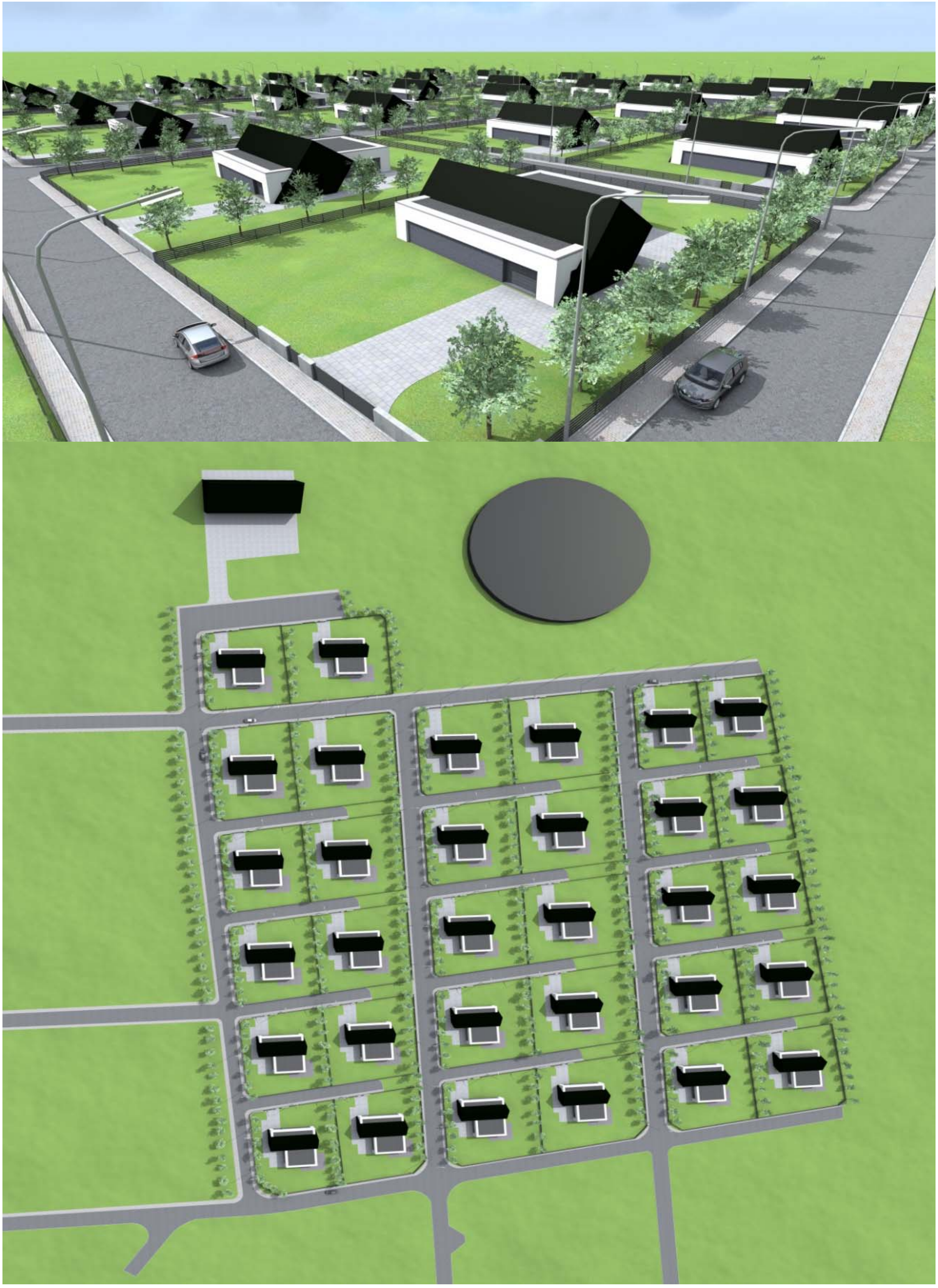

Figure 6. Single-family dwellings housing estate

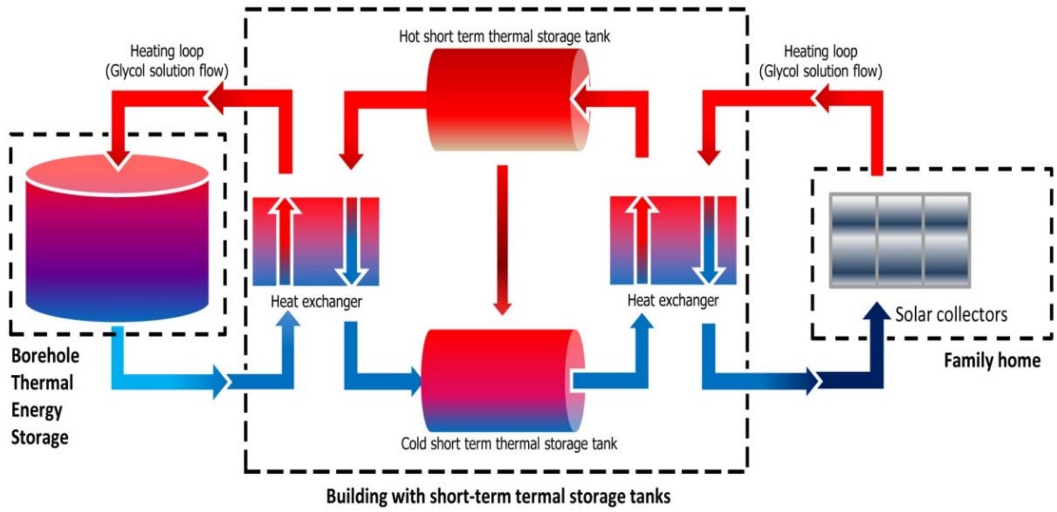

Figure 7. Diagram of a complete installation mode of thermal energy storage from the solar radiation

In case of energy generated for heating in the autumn-winter season from a ground accumulator system, the system operates in the opposite direction, as it is shown in Figure 8. In order to illustrate the operation of the system preliminary calculations are performed. They show that the demand for energy to heat the interior for such a housing estate (passive buildings) is in the year equal to 253 GJ. The theoretical amount of solar energy saved (without taking into account losses in the transmission line) is within a year (assuming a maximum efficiency of 65%) equal to 1172 GJ.

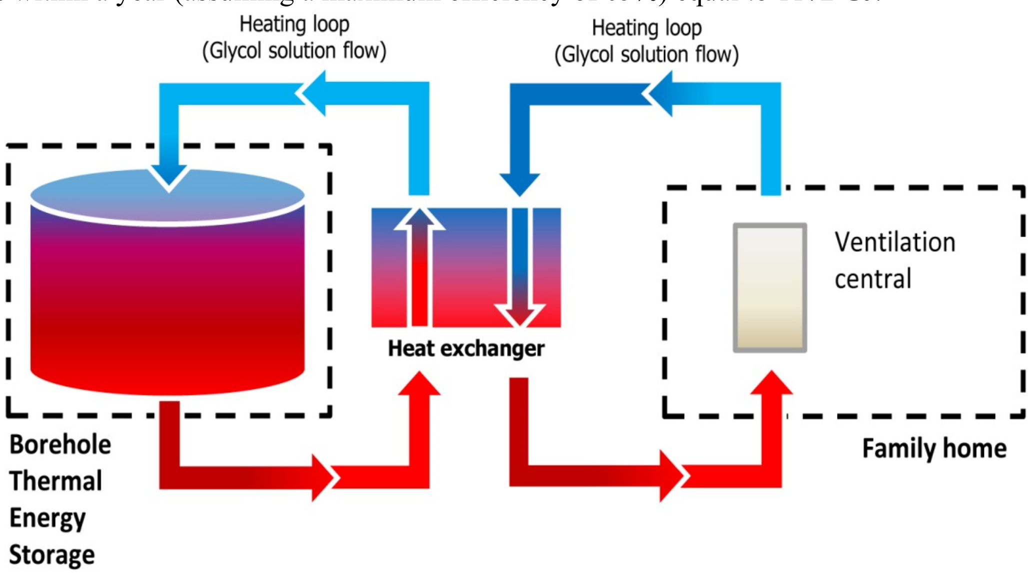

Figure 8. Diagram of a complete installation in a mode of thermal energy from the ground

Heat pumps that work with ground heat exchangers are devices that have one of the higher efficiency ratios among the existing nowadays heat pumps. Better results may be achieved only in the case of groundwater equipment application. The worst, from an energy efficiency perspective, are the solutions using atmospheric air as the bottom heat source. The results of the work have shown that the heat pump installation is used for air conditioning purposes and significantly (even by 25%) improves the efficiency of the air conditioning system. It implies that in this type of solution the top source of heat, in air conditioning systems is the ground rather than the air. Ground, during the summer, is characterized by a lower temperature than the air. All these factors make the economic balance of the heat pump installation more and more profitable. However, in order to achieve the best possible solution, the co-operation of the heating system with the air conditioning system should be taken into account at the design level of the building [14, 15, 16].

5. Conclusions

Due to the nature of its origin, the storage of solar thermal energy is justified in large heating installations. The first in the construction of large solar heating systems are the Scandinavian countries i.e. Sweden, Denmark and Finland, as well as the Netherlands, where such systems existed in the mid-80s of the 20th century. After another decade they are joined by the following countries: Germany, Austria, Switzerland, France and Uzbekistan. [11]. Poland, which is located in the moderate climate (not as cold as Scandinavia) has got a great potential in this field, but so far only small solar heating systems have been applied there. Suffering from shortage of thermal energy during the autumn and winter period, the economy has resorted mainly non-renewable energy sources. In the case of individual house holdings, they even use some harmful materials by which the environment and the people suffer by smog and other diseases.

Therefore, the surplus of solar radiation in the spring and summer, one should not only use currently, but also with time delay and in such a way need to improve and develop the technology of thermal energy storage. There are several interesting topics such as geological survey, groundwater level, system reliability, insulation of buildings and transmission lines, ease of operation and maintenance. There are just certain problems that come to the prospective designers of such systems. So, it is very important to implement some projects for monitoring and research of such heating systems. Therefore, in this paper the concept of settlement designed as a number passive residential houses, and its architectural visualization has been presented.

At present, it is possible to use close-circuit systems extracting heat from the ground and using heat pumps as support for conventional heat sources in order to heating single family houses or farms. As a conclusion it should be stated that every bit of energy obtained from clean source today is cleaner air and water tomorrow.

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