Збірник наукових праць. Серія: Галузеве машинобудування, будівництво
Academic journal. Series: Industrial Machine Building, Civil Engineering
http://journals.pntu.edu.ua/znp
https://doi.org/10.26906/znp.2019.52.1697

UDC 697.12/.14

Calculation of phace change heat accumulator in complex of energy efficient ventilation system

Kutniy Bogdan[1], Novakh Bogdan[2]*

[1] Poltava National Technical Yuri Kondratyuk University https://orcid.org/0000-0002-9016-5161
[2] PB «Euroclimate» https://orcid.org/0000-0003-0091-186X
*Corresponding author E-mail: bogdan.novah@gmail.com

The classification of the main seasonal heat energy storage batteries is given, and the modern circuit diagram of the phase shift battery as part of the system with a heat pump and a solar collector is considered. The disadvantage of water heaters is their large volume in most cases. By utilizing the accumulated latent heat of substances, a significant reduction in capital costs is achieved. The possibility of creating energy-saving ventilation systems with the use of a seasonal heat accumulator working on phase transformations of heat-accumulating material is considered. The linear stationary mathematical model of the battery thermal balance is made and on the basis of the calculation results graphs and diagrams are constructed enablingto analyze the work of the heat accumulator during the year. The classification of the main seasonal accumulators of thermal energy and ventilation systems with a ground heat exchanger use is considered. In the article the theoretical and computational research of the seasonal heat accumulator creation and application possibility working on phase transitions of heat-accumulating substances (water) in the ventilation system of a residential individual house is given.

Keywords: heat accumulator, energy efficient ventilation system, phase transition.

Розрахунок сезонного теплоакумулятора у складі енергоефективної системи вентиляції

Кутний Б.А.[1], Новах Б.Р.[2]*

[1] Полтавський національний технічний університет імені Юрія Кондратюка
[2] ПП «Евроклімат»
Адреса для листування E-mail: bogdan.novah@gmail.com

Наведено класифікацію основних сезонних акумуляторів теплової енергії та розглянуто сучасну схему роботи акумулятора фазового переходу у складі системи з тепловим насосом і сонячним колектором. Недоліком водяних акумуляторів тепла є те, що в більшості випадків вони займають великий об’єм. Шляхом застосування акумулюючих приховану теплоту речовин досягається значне зниження капітальних витрат. Розглянуто можливість створення енергозберігаючих систем вентиляції з використанням сезонного акумулятора теплоти, що працює на фазових перетвореннях теплоакумулюючого матеріалу. Розглянуто класифікацію основних сезонних акумуляторів теплової енергії та систем вентиляції із застосуванням ґрунтового теплообмінника. Складено лінійну стаціонарну математичну модель теплового балансу акумулятора й на основі результатів розрахунку побудовано графіки та діаграми, що дозволяють проаналізувати роботу теплоакумулятора протягом року. Прийняті спрощення у процесі моделювання полягають у тому, що рішення виконано для точкової задачі. Розв’язок здійснено з використанням логічних та математичних функцій на основі рівнянь, складеної математичної моделі. Наведено теоретичне і розрахункове дослідження можливості створення й застосування сезонного акумулятора теплоти, що працює на фазових переходах теплоакумулюючих речовин (води) у системі вентиляції житлового індивідуального будинку. Основні отримані результати полягають у тому, що у теплий період року акумулятор виконує роль вирівнювача амплітуди коливань температури, тим самим створюється можливість зменшити потребу в холоді для роботи системи кондиціонування повітря. Також доведено перспективну можливість зменшення маси теплоакумулюючого матеріалу за рахунок поперемінної зміни процесів заряджання-розряджання в акумуляторі у результаті добової зміни зовнішньої температури повітря у холодний період року, а саме її добового підвищення.

Ключові слова: теплоакумулятор, енергоефективна система вентиляції, фазовий перехід.

Introduction

Conventional water accumulators in most cases, as well as heat accumulators of rocks and earth, occupy a large volume. By using the accumulated latent heat of substances, a significant reduction in the cost of materials, as well as the required area for heat-storage facilities is achieved. It applies to low-temperature and high-temperature heat accumulators. It is due to fact that the heat-accumulating material is replaced without significant changes in the design of already existing heat accumulators. It can be done by placing in the reservoirs of accumulators heat-accumulating bodies of various forms (balls, thin cylinders, flat plates) [1].

In the article there is given the theoretical and computational research of the possibility of seasonal heat accumulator creation and application, working on phase transitions of heat-accumulating substances (for example water), as a constructive element of the ventilation system of a residential individual house.

Review of research sources and publications

The classification of the main known seasonal accumulators of thermal energy for today [1, 9, 10] is given. There are work circuits of year-round soil heat exchangers in the building ventilation structure [6, 7]. The principle scheme for the use of a heat pump with a phase change accumulator is known [2]. The use of phase change materials for the needs of life support systems for buildings and structures is considered (Fig. 1). These are: 1 -- The accumulation of hidden heat for heating the interior space of the premises; 2 -- Plaster and complex systems of facades with high specific accumulation capacity; 3 -- Translucent thermal isolation and daylight design; 4 -- Shaving phase transition materials in composite building systems; 5 -- Application of phase transition material in gypsum materials and paints; 6 -- Phase transitional materials in solar-air systems to stabilize their temperature mode of operation.

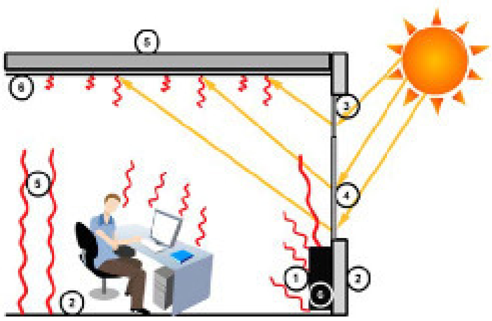

Figure 1 – Application of phase change materials in buildings and structures

Definition of unsolved aspects of the problem

Due to the cost constant growth of traditional energy resources, the massive installation of plastic windows is acutely a problem in the development of energy-efficient and low-cost ventilation systems of the building, especially in the winter period of the year. A well-designed and assembled ventilation system provides the necessary hygienic conditions in premises of the buildings and does not require much cash expenditures. The article aims are to explore the prospect of reducing the mass of heat-accumulating material by using the process of periodic recharging of the phase transition battery with warm air, which is possible due to the daily change in the temperature of the external air, namely its increase.

Problem statement

The main tasks of the work are: to carry out the calculation of the heat storage accumulator of the phase transition installed in the individual cottage during the season with the estimated time step of 3 hours using the linear mathematical model of the stationary heat transfer process; to determine the need for heat accumulating material (HAMs) and the temperature mode of the accumulator, assuming that the air temperature at the outlet of the battery is equal to the temperature of water or ice at the end of the heat exchange process for a certain period of time, that is, stationary mode is established; to consider the basic designs of the technical knowledge of seasonal thermal accumulators available at the present level; to investigate the possible temperature regime that occurs in the phase of accumulator change and to construct schedules for changing the absorbed and devoted energy during its operation over the year (one season).

Basic material and results

Recently, in the modern oversea market of engineering solutions, an energy-efficient scheme (Fig. 2) of the seasonal heat accumulator with a phase change with a heat pump use, an air solar collector and passive use of the Earth thermal energy, provided that the accumulation capacity is laid below the soil freezing zone, has appeared.

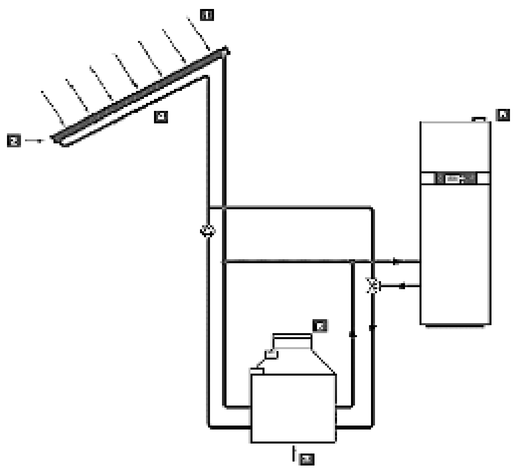

Figure 2 – Principle diagram of a heat pump with a solar collector and a phase change heat accumulator:

1 – solar heat; 2 – heat of air; 3 – heat of the earth; 4 – solar-air absorber; 5 – heat pump; 6 – thermal storage tank of the phase transition

The above method of using the heat-exchange circuit of a heat pump with a heat storage tank of the phase transition is completely ineffective because the tube icing dramatically reduces the heat output from the water, even though the higher thermal conductivity of the ice compared with the thermal conductivity of the water. Here it is necessary to consider the convection motion of water, because due to this movement the main heat exchange occurs in the liquid, but not at the expense of thermal conductivity.

If it is applied a heat exchange system of this type, then:

1) it is had to use an unreasonably long tube;

2) it is impossible to freeze all water in the heat accumulator due to the fact that the expansion of the ice leads to the depressurization of the container or the rupture of the heat exchange tube, which requires the application of special measures to prevent this negative phenomenon;

3) changing such a heat accumulator, it can be imagined that in a block of ice, the tube, which circulates the heat carrier, is depressurized, that leads to a complete stop of the heating system at the time of the thawing of the battery;

4) due to ice freezing of ice in this system, a low coefficient of efficiency is obtained;

5) the high final cost of the entire system is got due to the above-mentioned shortcomings.

Get warm in winter from the solar collector and heat the bottom of the heat accumulator due to the heat of the earth - are relevant and promising solutions, but the accumulator should be buried below the depth of the freezing zone of the soil, which in turn requires substantial investment. There can be also used low-potential waste heat from drainage and exhaust ventilation systems. Using these and other heat sources significantly reduces the amount of seasonal heat accumulator.

A seasonal or long-lasting heat accumulator requires a significant amount of accumulation material. This material should be inexpensive, have as high a heat capacity as possible and be non-toxic in terms of environmental impact. Another problem is the corresponding reservoir, which, in turn, should have good thermal insulation properties and a fairly rigid construction. Famous large-scale seasonal heat accumulators can be divided into the following types [3, 4, 8]:

- water pools and reservoirs (natural or artificial);
- ground accumulators (with vertical or horizontal heat exchangers);
- aquifers (filled with water by porous geological formations).

Widespread distribution in ventilation systems for preheating and cooling of the inflow air acquire soil heat exchange contours [7], Fig. 3. However, during the operation, the problem of choosing the material of the battery pipes is acute, as they are subject to complex "freeze-thaw" processes on the outer surface and icing in the winter and the formation of condensation in the summer on the inner surface. The need to control the purity of the tidal air - the formation of condensate is an enabling environment for the development of various pathogenic micro-organisms. Considering capital installation and construction costs, the difficulty of installing a coil of pipes laid down below the soil freezing zone.

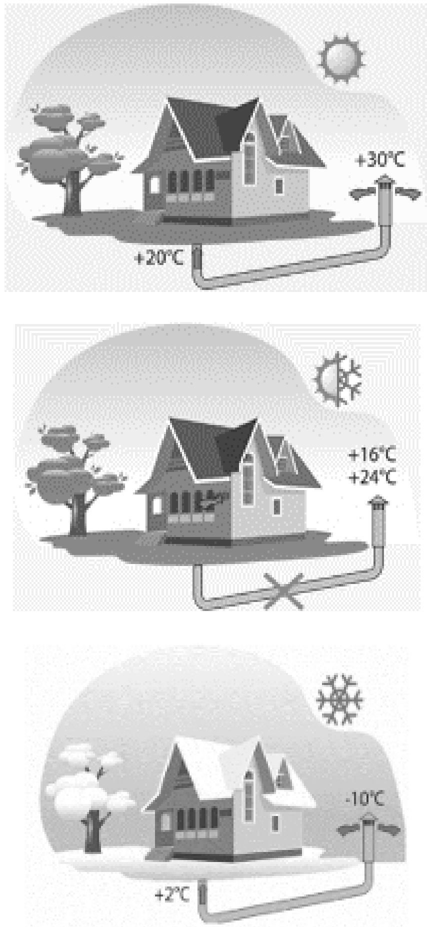

Figure 3 – Different operating modes of the ground heat exchanger GHE (from up to down: summer, shoulder period and winter)

In order to investigate the prospective possibility of using a thermal battery for phase transition in domestic ventilation systems and assessing its energy efficiency during one season (year), it is considered its application for the needs of providing fresh air to the premises of an individual dwelling house (cottage) with a total living area of 100 m2.

Total air flow rates for an individual dwelling house are

$$L_{tot}= L_r+ L_c+ L_t, \quad (1)$$

where $L_r = F{\cdot}K$ and L_c, L_t – the value of air exchange, respectively, for living rooms, kitchens and detached lavatory, taken in accordance with the norms [10], m^3;
F – area of living rooms, m^2;
K – multiplicity of air exchange, 1/our.

The system time is 720 hours per month. The estimated internal air temperature in the living rooms is + 18 ° C. The temperature of the inflow air can be reduced by 3 ° C, considering that the air is distributed through a grid located under the ceiling of the room. The total air exchange for a home is:

$$L_t = 100 + 90 + 50 = 240 \text{ m}^3/\text{our}.$$

Output values of the outside air initial temperature are taken according to [5] over a period of 3 hours for the town of Poltava for 2015 (correspondingly, and increase in the amount of air for a 3-hour increment). The initial mass of heat-accumulating material (water) was taken at 4.5 tons and in the process of computer calculation has been clarified. The initial temperature of the working material for December 31.12.2015 is assumed to be 5.1 °C. Simplifications are accepted, namely, the solution is made for the point problem, that is, the battery is at a certain time, either water or ice. The solution was implemented using MS Excell software using logical and mathematical functions based on the equations given and obtained below in the presented work.

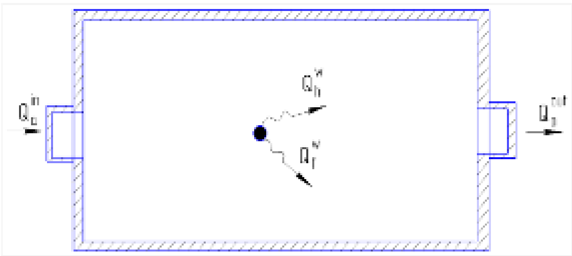

Figure 4 – Graphical representation of heat flows in a heat accumulator: Q_a^{in}, Q_a^{out} - respectively, the thermal flows of the inlet and outlet air; Q_h^w,Q_f^w is the explicit and hidden heat of the phase-accumulating material, respectively

The model diagram of heat flows in the thermal accumulator is plotted (Fig. 4) and from the heat amount thermal balance equation of air, water and ice the formula for the final temperature of water, °C is determined:

$$\begin{cases} IFM_1 = 0 \rightarrow c_a \times G_a \times (t_a^k - t_a^n) \times \tau = c_w \times M_w \times (t_w^n - t_w^k) \\ c_a \times G_a \times (t_a^k - t_a^n) \times \tau = K \times F \times \left(\dfrac{t_w^n + t_w^k}{2} - \dfrac{t_a^n + t_a^k}{2} \right) \\ \\ IFM_1 < M_w \rightarrow c_a \times G_a \times (t_a^k - t_a^n) \times \tau = r \times \Delta m_1; \\ t_w^n = t_w^k = t_f^w = 0 \\ c_a \times G_a \times (t_a^k - t_a^n) \times \tau = K \times F \times \left(0 - \dfrac{t_a^n + t_a^k}{2} \right) \\ \\ IFM_1 = M_w \rightarrow c_a \times G_a \times (t_a^k - t_a^n) \times \tau = c_1 \times M_1 \times (t_1^n - t_1^k) \\ c_a \times G_a \times (t_a^k - t_a^n) \times \tau = K \times F \times \left(\dfrac{t_1^n + t_1^k}{2} - \dfrac{t_a^n + t_a^k}{2} \right) \end{cases} \quad (1)$$

where c_w, c_i – heat capacity of water and ice, kJ/kg·°C;

t_w^n, t_w^k – respectively, the initial and final water temperature, °C;

t_a^n, t_a^k – respectively, the initial and final air temperature, °C;

$r = 336$ – hidden heat of melting and crystallization, kJ/kg,

M_w, M_I – respectively, the mass of water or ice in the heat accumulator, kg;

Δm_1 – amount of formed ice as a result of leakage of heat exchange processes, kg,

c_a – heat capacity of air, kJ/kg·°C;

G_a – mass flow of supply air, kg/s;

t_1^n, t_1^k – respectively, the initial and final ice temperature, °C,

t_f^w – temperature of the phase transition of the heat-accumulating material (water), °C;

F – the area of the heat-exchange surface of the capsules with the material, m^2;

K – heat transfer coefficient, W/m^2°C,

τ – time settlement interval, s.

Since stationary heat transfer process, it is got:

$$\begin{aligned} & IFM_1 = 0 \rightarrow t_w^k = t_w^n - \frac{c_a \times G_a \times (t_a^k - t_a^n) \times \tau}{c_w \times m_w}; \\ & IFM_1 < M_w \rightarrow t_w^k = t_w^n = t_f^w = 0; \\ & IFM_1 = M_w \rightarrow t_1^k = t_1^n - \frac{c_a \times G_a \times (t_a^k - t_a^n) \times \tau}{c_1 \times m_1}. \end{aligned} \quad (3)$$

The summary mass of ice (M_I) formed as a result of heat exchange between cold air and water from i=1 to n – all estimated time intervals, kg:

$$\begin{cases} \Delta m_1 = \dfrac{c_a \times G_a \times (t_a^k - t_a^n) \times \tau}{r}; \\ M_1 = \sum\limits_{i=0}^{n} \Delta m_1 \end{cases} . \quad (4)$$

The results of modeling the thermal mode of the thermal battery are shown in the graph (Fig. 5).

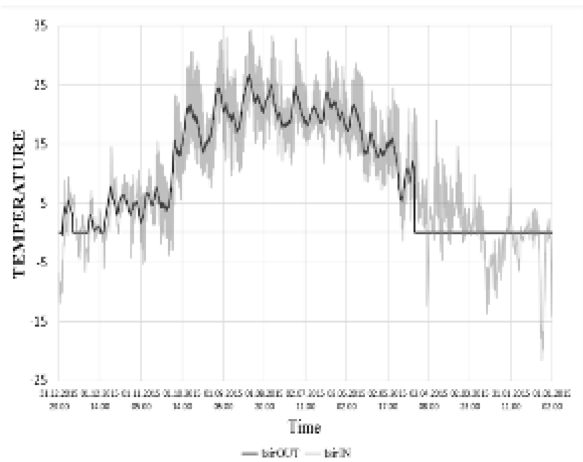

Figure 5 – Chart of the external temperature and air temperature at the outlet of the heat accumulator every 3 hours

From the graph it is clear that the temperature of the air after processing in the phase transition accumulator in the winter period of the year is maintained at not less than 0 ° C, which enables to increase the supply air to the room in the recuperator to the desired temperature and prevent the icing of the above heat exchanger. In the warm period of the year, the accumulator carry out a pivotal role in the stabilizer of the amplitude of temperature fluctuations, which reduces the cost of cooling energy for the needs of the air conditioning system.

The graph of changes in the amount of water and ice present at a certain time in a phase-change accumulator is shown below (Fig. 6).

Analyzing the chart above, it can be stated that with a more detailed calculation, the need for heat accumulating material drops is due to alternating changes in charging and discharging of the accumulator during the year. As a result, the weight of water in the battery decreases.

Diagram showing the change in the thermal mode of the battery for the study season is shown in Figure 7.

In the graph above the zero is shown the process of charging, that is, the amount value of heat absorbing HAM (water) in the process of charging; below zero is the process of discharging, namely, the amount of heat that emits water or cooling, or as a result of a change in aggregate state, turning into ice. In this case, the outside air is either cooled or heated, respectively. Also, the alternation of the heat exchange processes occurring in the battery is clearly visible.

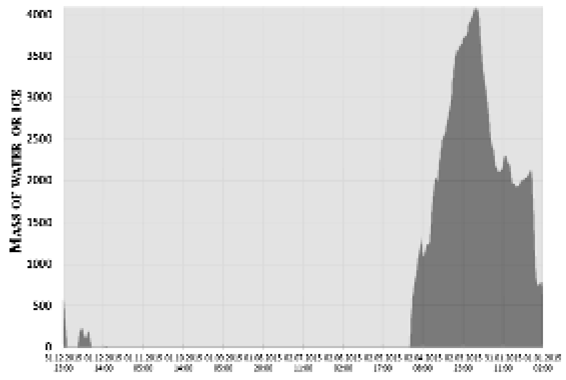

Figure 6 – Diagram of water and ice distribution in the heat accumulator
(black-mass of ice; gray – mass of water)

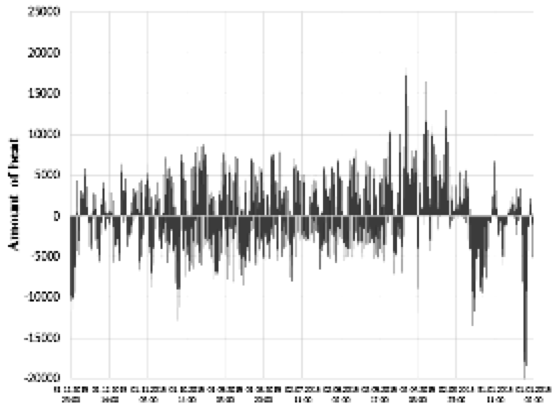

Figure 7 – Diagram of the heat accumulated in the heat accumulator amount distribution

Conclusions

1. The classification of the main seasonal heat accumulators is given. The diagrams of the work of the soil heat exchanger in different periods of the year are presented. The system consisting of a phase change accumulator and the heat transfer circuit of the heat pump enclosed in it are described; the main shortcomings of the above-mentioned engineering solutions are given.

2. With a more detailed hourly calculation, it is possible due to the alternating change of charge-discharge processes in the accumulator to reduce the need for heat-accumulating material more than twice.

3. Based on the calculations using the mathematical model of thermal balances of water, ice and air, a diagram of the distribution of air temperature after treatment in the accumulator, diagram of the formation of ice and the amount of accumulated heat was constructed and analyzed.

4. In the warm period of the year, the acumullator acts as an equalizer of the temperature fluctuation amplitude thereby creating the ability to reduce the need of the cold energy for the needs of the air conditioning system. The promising possibility of reducing the mass of heat-accumulating material from 9 to 4 tons is proved.

References

1. Кенисарин, М.М., Карабаев, М.К. (1987). *Централизованные системы солнечного теплоснабжения с сезонным аккумулированием тепла (обзор).* Ташкент: УзНИИТИ.
2. *Viessmann.com.ua* [Інтернет-сервіс]. Режим доступа: http://viessmann.com.ua
3. Гулиа, Н.В. (1980). *Накопители энергии*. Москва: Наука.
4. Viloh, Yu. & Tojber, V. (1981). Accumulation of heat by using the hidden heat of melting of substances. *Stadt-und Gebäudetechnik*, 35(11), 326-328.
5. Rp5.ua. Режим доступа: www.rp.ua (дата звернення 30.05.2019).
6. Florides, G. & Kalogirou, S. (2007). Ground heat exchangers -A review of systems, models and applications. *Renewable Energy*, 32(15), 2461-2478. https://doi.org/10.1016/j.renene.2006.12.014
7. Soni, S., Pandey, M. & Bartaria, V. (2015). Ground coupled heat exchangers: A review and applications. *Renewable and Sustainable Energy Reviews*, 47, 83-92. https://doi.org/10.1016/j.rser.2015.03.014
8. Andersson, O. & Hägg, M. (2008), *Deliverable 10 - Sweden - Preliminary design of a seasonal heat storage for ITT Flygt, Emmaboda, Sweden*. Integration of geothermal energy into industrial applications (IGEIA).
9. Turgut, B., Dasgan, H.Y., Abak, K., Paksoy, H., Evliya, H. & Bozdag, S. (2009). Aquifer thermal energy storage application in greenhouse climatization. *Acta Hortic*. 807, 143-148. https://doi.org/10.17660/ActaHortic.2009.807.17
10. ДБН В.2.2-15:2015. *Житлові будинки. Основні положення* (2015). Держбуд України.

1. Kenisarin, M.M. & Karabaev, M.K. (1987). *Centralized solar thermal systems with seasonal heat storage (overview).* Tashkent: UzNIITI.
2. *Viessmann.com.ua* [Internet resourse]. Access mode: http://viessmann.com.ua
3. Gulia, N.V. (1980). *Energy storage*. Moscow: Science.

4. Viloh, Yu. & Tojber, V. (1981). Accumulation of heat by using the hidden heat of melting of substances. *Stadt-und Gebäudetechnik*, 35(11), 326-328.

5. Rp5.ua [Internet resourse]. Access mode: www.rp.ua (date of appeal 30.05.2019).

6. Florides, G. & Kalogirou, S. (2007). Ground heat exchangers -A review of systems, models and applications. Renewable Energy, 32(15), 2461-2478. https://doi.org/10.1016/j.renene.2006.12.014
7. Soni, S., Pandey, M. & Bartaria, V. (2015). Ground coupled heat exchangers: A review and applications. *Renewable and Sustainable Energy Reviews*, 47, 83-92. https://doi.org/10.1016/j.rser.2015.03.014
8. Andersson, O. & Hägg, M. (2008), *Deliverable 10 - Sweden - Preliminary design of a seasonal heat storage for ITT Flygt, Emmaboda, Sweden*. Integration of geothermal energy into industrial applications (IGEIA).
9. Turgut, B., Dasgan, H.Y., Abak, K., Paksoy, H., Evliya, H. & Bozdag, S. (2009). Aquifer thermal energy storage application in greenhouse climatization. *Acta Hortic*. 807, 143-148. https://doi.org/10.17660/ActaHortic.2009.807.17

10. DBN V.2.2-15:2015. *Residential buildings. Basics* (2015). State building of Ukraine.