Assessment of Economic Advantages of Solar Energy for Manufacturing of Concrete Elements

***[1]Dmitry D. Koroteev, [2]Makhmud Kharun, [3]Tatiana A. Suetina**

[1] Department of Architecture & Civil Engineering, Peoples Friendship University of Russia (RUDN University), Moscow, Russia

[2] Department of Architecture & Civil Engineering, Peoples Friendship University of Russia (RUDN University), Moscow, Russia

[3] Department of Hydraulics, Moscow Automobile & Road Construction State Technical University (MADI), Moscow, Russia

Corresponding Author: Dmitry D. Koroteev
Email: d241184@gmail.com

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Abstract

One of the main guarantees of sustainable development of the civilization nowadays is settlement of the energy problem. People will encounter the crisis, connected with the reduction of the modern rate of production due to the depletion of fossil fuels without introduction of energy-saving technologies and renewable energy resources.

The research work is devoted to reduction of the fossil fuels consumption in manufacturing of concrete elements and replacement them by solar energy, which can be used for heat treatment of concrete. Transformation to the renewable energy resources is associated with economic costs, which seem unjustified without taking into account its social and ecological aspects.

The aim of the research work is to develop the methodic of economic assessment of the solar energy use for the manufacturing of concrete elements, taking into account its social and ecological advantages.

The developed methodic includes equitation for determination: of the cost of yearly saving of fuel and energy resources during operation of solar energy equipment; the nonrecurring cost of production and installation of the solar energy equipment; ecologic and social components of the converted economic costs.

The economic assessment shows that yearly replacement of fossil fuels by solar energy is 40-60% in dependence on the geographic area of manufacturing of concrete elements. The yearly economic benefit from replacement of fossil fuels is 60-85 tons of oil equivalent for the plants with manufacturing capacity of 20000 m^3*, 150-200 tons of oil equivalent for the plants with manufacturing capacity of 50000* m^3*.*

Keywords : Solar Energy, Renewable Resources, Concrete Elements, Heat Treatment, Economic Assessment

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I. Introduction

Civil engineering is one of the most energy consumption sectors of economy of many countries. It includes energy demand for construction process and buildings life cycle (Berardi, 2017; Brady and Abdellatif, 2017, Refahi and Talkhabi, 2015). Concrete, as the most common construction material in the world, and concrete elements have considerable energy requirements for their manufacturing, including energy expenses for heat treatment of concrete to speed up the process of its curing (Braga et al., 2017). Fossil fuels, such as natural gas, oil, coal are required for this purpose.

Reduction of fossil fuels consumption and their replacement by renewable energy resources is vital problem nowadays for all fields of the world economic system (Abdullah et al., 2015, Amri, 2017, Foster et al., 2017). In 2002, the World Summit on Sustainable Development in Johannesburg after detailed discussion specified five main fields of ecology saving activity: fresh water and sanitation, energy, health, agriculture and biological diversity. In particular, the Danish prime minister summarized the results of the discussion "… at present, as ever, choice, which stands against the world, is collective future, otherwise the future will not have been at all" (Johannesburg Declaration, 2002).

Surveys of scientists, carried out in 50 countries of the world in the context of preparation of the summit in Johannesburg, specified more than 30 global destructive factors, endangering human beings. The main factors include: depletion of fossil fuels; breaking of energy balance of the Earth; pollution of environment and so on. Thus, until recent times, the problem consisted of the assessment of the compromise between the natural resource use and the ecologic saving activities. Nowadays, scale of irrevocable and uncompensated destruction of environment by human beings exceeds dangerous indication. Now, discourse can be carried out only about relative and then absolute minimization of the fossil fuels consumption and environmental pollution (Foley, 2017; Romano et al., 2017; Gasparatos et al., 2017).

The main urgent measures, according to opinion of the scientists, include:

- saving of surviving ecosystems and recovery of damaged ecosystems;
- introduction of energy saving technologies and renewable energy resources.

Taking into account the above, our research work is devoted to reduction of fossil fuels consumption in manufacturing of concrete elements and replacement them by solar energy, which can be used for heat treatment of concrete.

However, the transformation to renewable energy resources is associated with economic costs, which seem unjustified without taking into account its social and ecological aspects (Hansen et al., 2017; Silva et al., 2013). In this case, the aim of the research work is to develop the methodic of economic assessment of the solar energy use for the manufacturing of concrete elements, taking into account its social and ecological advantages.

II Solar energy as alternative energy resource

Temperature of concrete elements, which are heated by solar energy, can reach 60-80 °C. However, it influences negatively on the final strength of concrete, curing without care in such conditions (Benammar et al., 2013; Koroteev et al., 2017).

Solar energy equipment allows speeding up the process of concrete curing and limiting mass transfer with environment. There are different types of solar energy equipment, but the solar energy equipment like solar collector and hotbox are most suitable for manufacturing of precast concrete elements.

The solar energy equipment like solar collector is a formwork with transparent cover, where concrete is direct heated by solar energy in the daytime and stores heat in the nighttime (O'Hegarty et al., 2017; John et al., 2013). The solar energy equipment like hotbox is a rectangular metal container without bottom with transparent cover, fixed around it, and thermal insulation of the container part, oriented to the North (fig. 1). The heat taking material, which absorbs solar radiation and becomes the energy source, is placed inside of the solar energy equipment.

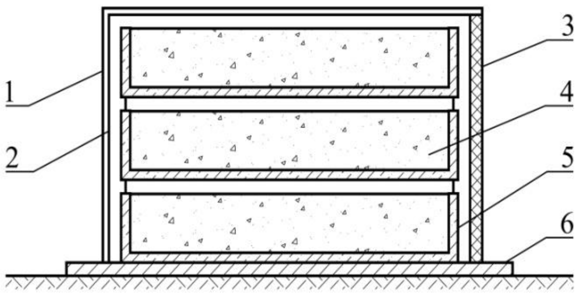

Fig. 1: Concept of the hotbox solar energy equipment

1 – transparent cover, 2 – metal container, 3 – thermal insulation of the container's part, oriented to the North,
4 – concrete, 5 – formwork, 6 – stand.

However, it is necessary to take into account real cost of energy resources, reflecting real expenses for their production to compare correctly technologies, using solar energy and fossil fuels.

The amount of crude oil, which is consumed in the world every year, exceeds its creation in natural conditions for two millions years. Giant rate of the fossil fuels consumption at rather low price, which does not reflect the real total society expenses, leads to the impossibility of its using in the next stages of the production development (Stram, 2016).

The consumed fossil fuels have a maximum value from the position of longstanding economic development. In future, its price will increase inevitably, because the distant fields of fossil fuels are involved in the production turnover, therefore expenses for exploration works and creation of the infrastructure, transportation expenses are rising. It is the first component of costs, which we pay for energy, but they are not reflected in the market price (Aguirre et al., 2014).

The other component of the fossil fuels price, distributed to the whole society but not included in the energy rates, is related with the pollution of environment during its using. The world assessments of the direct social expenses, connected with the pollution impact, including diseases and human lifetime decline, harvest decline, the forests recovery and buildings renovation in the result of air, water and soil pollution, give us about 75% of the world prices for fuel and energy. These expenses should be taken into account during the determination of the energy price.

The difference of the impact to the environment makes the fossil fuels saving technologies incomparable with the tradition technologies even in case of all other identical parameters.

We can consider the renewable resources as a part of the environmental saving activities, which aim is the recovery of the original environment characteristics. It is necessary to consider the limited ability of the environment to destroy exhaust and regenerate the renewable resources as a limiting factor of the economic growth.

III. Results and discussion

One of the visual economic indicators of the company activity, showing its competitiveness, the development level of manufacturing, reasonability of using technologies, is product cost. Product cost is cost estimation of fuel and energy, raw materials, main funds, labor resources and other expenses for its production and distribution.

The decline of concrete elements cost during their manufacturing with the use of solar energy is carried out by saving fuel and energy resources, consumed for heat treatment of concrete (1):

$$\Delta C = C_e = C_1 - C_2 \tag{1}$$

where C_1 – cost of products, manufactured with the use of fossil fuels, \$; C_2 – cost of products, manufactured with the use of solar energy, \$; C_e – cost of saved fuel and energy resources, \$.
We can determine the cost of saved fuel and energy resources according to formula (2):

$$C_e = \alpha\left(C_y T_p - C_n\right) \tag{2}$$

where α – coefficient, taking into account energy costs for the fuels production; C_y – cost of yearly saving of fuel and energy resources during operation of solar energy equipment, \$; C_n – nonrecurring cost for production and installation of solar energy equipment, \$; T_p – period of cost recovery for production and installation of solar energy equipment.

The period of cost recovery for production and installation of solar energy equipment can be determined by formula (3):

$$T_p = \frac{C_n}{C_y} \tag{3}$$

The cost of yearly saving of fuel and energy resources during operation of solar energy equipment for the manufacturing of concrete elements is determined by the amount of saved fossil fuels (in energy and financial equivalent) and the cost reduction for the operation of heat equipment in view of expenses for maintenance of solar energy equipment. It can be determined according to formula (4):

$$C_y = C_f + C_t - C_s \tag{4}$$

where C_t – yearly cost for the operation of heat equipment, including expenses for its maintenance, transportation of fossil fuels, cost of energy, losing in damaged thermal systems and necessary for boiler plant means, $; C_s – yearly cost of the operation of solar energy equipment, $; C_f – yearly cost of fossil fuels, saved with the use of solar energy as the source of energy for heat treatment of concrete.

We can determine the yearly cost of fossil fuels, saved with the use of solar energy as the source of energy for heat treatment of concrete by formula (5):

$$C_f = \beta \cdot P_f \cdot E_y \tag{5}$$

where P_f – price of fuel, $; β – average fuel equivalent to convert natural fuel to conditional fuel (table 1); E_y –yearly saving of fossil fuels with the use of solar energy, J.

Table 1: Average fuel equivalent for different types of fossil fuels

Type of fossil fuels	Unit of measure	Fuel equivalent
Coal	ton	0.7
Peat	ton	0.45
Fuel wood	m^3	0.2
Oil	ton	1.45
Natural gas	1000 m^3	1.15

The yearly saving of fossil fuels with the use of solar energy is equal to the amount of energy, consumed by concrete due to impact of solar energy during the period of its effective using. It can be determined according to formula (6):

$$E_y = F_s \cdot P(n) \cdot \sum_{i=1}^{n} E_{c(i)} \tag{6}$$

where n – prognosticated number of days in a year of the effective use of solar energy for heat treatment of concrete; $P(n)$ – probability of the effective work of solar energy equipment for the considered period; $E_{c(i)}$ – amount of energy, consumed by concrete per day in the solar energy equipment with useful size of 1 m^2, J; F_s – useful size of the solar energy equipment, m^2.
The cost of energy, losing in damaged thermal systems, is determined by formula (7):

$$C_l = 3{,}432 \cdot 10^{-6} \cdot 1{,}2 \cdot E_{th} \cdot l \cdot n \qquad (7)$$

where E_{th} – amount of energy, losing in damaged thermal systems, J; l – size of the thermal systems equipment, m; n – amount of the thermal systems equipment.
We can determine the cost of fossil fuels, used for boiler plant means according to formula (8):

$$C_b = \kappa_1 \cdot \kappa_2 \cdot \kappa_3 \cdot \left(C_f + C_l\right) \qquad (8)$$

where k_1 – coefficient, taking into account types of fossil fuels (for solid fuel k_1=0,06, for natural gas k_1=0,03); k_2 – coefficient, taking into account specific consumption of energy for heat treatment; k_3 – coefficient, taking into account specific consumption of energy for production of electricity.
The cost for transportation of fossil fuels from the production site to the plant, which manufactures concrete elements, can be determined by formula (9):

$$C_{tr} = 2 \cdot l_{tr} \cdot \left(C_f + C_l + C_b\right) \cdot 10^{-4} \qquad (9)$$

where l_{tr} – distance between the production site and the site of fossil fuels consumption, km.
Cost for maintenance of the solar energy equipment includes expenses for routine maintenance, replace of faulty parts for the solar energy equipment and other works, which is necessary to keep the equipment in operating condition. The energy expenses for installation and dismantling of the solar energy equipment are determined according to the fixed production capacity of the installed electrical equipment.
The nonrecurring cost of production and installation of the solar energy equipment in the plant, which manufactures concrete elements, can be determined according to formula (10):

$$C_n = C_{n1} + C_{n2} + C_{n3} \qquad (10)$$

where C_{n1} – cost for installation of the solar energy equipment, \$; C_{n2} – cost for production of the solar energy equipment, \$; C – transportation cost for delivery of the solar energy equipment from the production site to the consumption site, \$.
The assessment of efficiency of the solar energy using is to be characterized with energy, economic and social-economic component. In this case, usual assessment methodic of efficiency of new technologies does not take into account the advantages

of renewable energy resources, connected with level of their impact to the environment.
The social-economic component includes economic assessment of social and ecological results, reached with saving of fossil fuels during exploitation of the solar energy equipment. An index of converted economic costs is used to determine the social-economic component. The index allows taking into account in explicit form not only economic result, but social and ecological result of the new technologies using.
The converted economic costs include the following components for each possible ways of production (11):

$$C_{cec} = C_{tc} + C_{ec} + C_{sc} \tag{11}$$

where C_{tc} – technological component, reflecting costs for production and operation of the considered technologies, which includes the product cost and standardized deductions from capital investments, \$/year; C_{ec} – ecological component, reflecting costs for environmental management, \$/year; C_{sc} – social component, reflecting costs for social insurance, nonrecurring and current expenses for treatment, decline of the human life productive period in connection with the diseases from exhausts and other factors, affecting human health, \$/year.
Accordingly, efficiency of the use of solar energy as energy for heat treatment of concrete elements is determined by formula (12):

$$\Delta C = C_{ff} - C_{se} \geq 0 \tag{12}$$

where C_{ff} – converted economic costs of the fossil fuels using for heat treatment of concrete, \$; C_{se} – converted economic costs of the solar energy using for heat treatment of concrete, \$.
In the usual assessment methodic, the social and ecological components are determined with standard coefficient of efficiency of capital investments (in isolation from specific features of compared variants). In the result, quantitate relationship between capital and labor components of converted economic costs changes, therefore the advantages of less time consuming variants rise. The economic method of assessment of efficiency of capital investments determines not only benefits, which can be reflected in the cost form, but also benefits, which can be reflected in the real form. Even using the perfect economic methods of assessment, we cannot reflect all variety of benefits of capital investments to the national economy.
The ecologic component takes into account costs, connected with the environmental management, including decline of losses, connected with exhaust. At present, we have not reliable information to calculate the ecological component.
In the most industrial countries losses from exhaust are 3-5% of the gross domestic product, in the result, costs of environmental management reach 1-3%. The costs of environmental management in the various industrial sectors reach 5-20% of total capital investments.

The usual assessment method determines losses from exhaust if its amount is more than the maximum permissible limits. Therefore, it is advisable to consider exhaust as the one of real parameter.

The ecologic component of the converted economic costs is determined according to formula (12):

$$C_{ec} = L_{ee} \cdot B \cdot (1 + k_{et} + k_{es} - f) \quad (12)$$

where f – share of fossil fuels, which can be replaced by solar energy; B – yearly consumption of conditional fuel for heat treatment of concrete, ton/year; k_{et}, k_{es} – dimensionless coefficients, characterizing nonrecurring expenses of fuel, connected with production of the traditional equipment and the solar energy equipment; L_{ee} – relative losses from exhaust in the cost form, \$/ton.

It can be determined by formula (13):

$$L_e = \gamma \cdot G \cdot \varphi \cdot M \quad (13)$$

where γ – constant, changing in accordance with fuel prices, G – coefficient of relative risk, depending on type of area, φ – coefficient, taking into account volume of exhaust in the atmosphere, M – relative weight of yearly exhaust from the source of pollution, conditional fuel/ton.

The social component of the converted economic costs can be determined according to formula (14):

$$C_{es} = L_{es} \cdot (1 + k_{st} + k_{ss} - f) \quad (14)$$

where L_{es} – relative social losses from exhaust in terms of unit of produced energy, \$/J; k_{st}, k_{ss} – dimensionless coefficients, characterizing social losses, connected with production of the traditional equipment and the solar energy equipment.

The determination of the social and ecologic components has assessment feature, because at present we have not correct information for the most components, used in this calculation.

IV. Conclusion

The economic efficiency of the use of solar energy for heat treatment of concrete elements, as the energy efficiency, depends on many factors. The main factors are climatic conditions, organizational and technological conditions of manufacturing, manufacturing schedule and range of products.

The determined economic assessment points that yearly replacement of fossil fuels by solar energy is 40-60% in dependence on the geographic area of manufacturing. The yearly economic benefit from replacement of fossil fuels by solar energy for manufacturing of concrete elements is 60-85 tons of oil equivalent for the plants with manufacturing capacity of 20000 m^3, 150-200 tons of oil equivalent for the plants with manufacturing capacity of 50000 m^3. The yearly economic benefit has been determined under condition that the average yearly production is 6-7 m^3 of concrete elements from one m^2 of manufacturing site.

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