doi: 10.18720/MCE.78.5

Payback period of investments in energy saving

Период возврата инвестиций в энергосбережение

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Key words: civil engineering; buildings; energy resources; energy consumption; operating costs; investments; return of investments; payback period; energy efficiency; energy saving

Ключевые слова: строительство; здания; энергетические ресурсы; энергопотребление; эксплуатационные затраты; инвестиции; окупаемость инвестиций; срок окупаемости инвестиций; энергетическая эффективность; энергосбережение

Abstract. Authors developed a mathematical model for estimating the discounted payback period of investments for reducing energy resources needed in building's development. Obtained equations allow calculating the projected payback period for investments in energy saving, taking into account the size of the investment, the estimated or actual value of the achieved energy saving effect, the dynamics of energy carriers tariff growth, the discounting of future cash flows, and also a value and a period of loan repayment. The proposed mathematical model allows to perform quickly and efficiently a comparison of various energy-saving solutions based on economic viability and choose the most optimal from them.

Аннотация. Разработана математическая модель оценки дисконтированного срока окупаемости инвестиций, направленных на уменьшение потребляемых в здании энергетических ресурсов. Получены уравнения, позволяющие выполнить расчет прогнозируемого срока окупаемости инвестиций в энергосбережение с учетом размера инвестиций, расчетного или фактического значения достигаемого энергосберегающего эффекта,величины денежного потока, достигаемого в результате реализации энергосберегающих мероприятий, динамики роста тарифов на энергоносители, дисконтирования будущих денежных потоков, а также величины и срока возврата кредитных средств. Предложенная математическая модель позволяет быстро и качественно произвести сравнение экономической эффективности различных энергосберегающих решений и выбрать из них наиболее оптимальное.

1. Introduction

Ensuring the energy efficiency of designed buildings is an important government's goal, reflected in the EPBD directive and modern energy saving requirements. However, no less urgent task is to reduce energy consumption in existing buildings. Most of the existing buildings were built before the implementation of modern energy-saving programs. For this reason, the amount of energy consumed in those buildings is much higher compared to new buildings.

One of the effective ways to reduce energy consumption in existing buildings is the implementation of a set of energy-saving measures. It can be achieved by building envelop heat insulation [1–3], improving the integrity of building structures [4, 5], implementing efficient engineering equipment [6–10], using secondary energy resources and renewable energy sources [11–15]. Energy-saving measures usually lead to the reduction of energy consumption in buildings and, consequently, to the reduction of operating costs, for example, for heating.

However, the implementation of any energy-saving event requires investments. Investments in energy saving usually are lump-sum costs. Reduction of operating costs, achieved as a result of the implementation of a set of energy-saving measures, will take place over the next several years, i.e. the profiting component of investment is spread in time.

After a certain period of time, the total economic effect achieved as a result of the introduction of energy-saving technical solutions can reach the value of the initial investment. This time period should be considered as predictable period of their payback.

If the payback period of investments is shorter than the estimated service life or operation of the implemented technical solution, it should be considered as economically justified.

The main criteria for assessing the effectiveness of investments are:

- Simple payback period (*SPP*);
- Discounted payback period (*DPP*).
- Accounting Rate of Return (*ARR*);
- Net Present Value (*NPV*);
- Profitability Index (*PI*);
- Internal Rate of Return (*IRR*).

The above criteria for assessing the effectiveness of investment and construction processes are described in details in [16–32].

The analysis of the economic viability of investments in energy saving is presented in [6, 33–35].

In the article [33], in a case of a public school building, simple and relatively inexpensive measures aimed at energy saving are considered. The authors evaluated the environmental benefits achieved as a result of planned activities and calculated a simple payback period for investments.

The research [34] presents the results of the European project RePublic-ZEB. Its goal is the energy modernization of two existing public buildings. The aim of the research is to promote not only energy-efficient, but also cost-effective technical solutions. The research presents results as a "package of activities", calculation of energy consumption, global costs, actual payback period and CO_2 emissions.

In [35] authors investigated the energy consumption of office buildings equipped with heat pumps. Based on the analysis of the results of energy audit, the authors proposed measures for the modernization of existing heat pumps and calculated a simple payback period for investments.

The research [6] presents an economic analysis of energy-saving technologies implemented in a complex production building. The return on investment model includes combination of simple return and cost analysis of the life cycle.

In [36, 37], more complicated models of return on investment are considered.

The research [36] carried out estimates of the economic viability of energy-saving measures implemented in public buildings. The methodology is based on a sample of 36 actions. The model is designed to find conditions that ensure the profitability of the project. Financial analysis is integrated with risk analysis, which allows to evaluate the sensitivity of the results to the original model data.

In [37] the authors consider various scenarios for financing energy-saving measures aimed at reducing energy consumption in existing residential buildings, taking into account the size of the initial investment, the availability of the investor's own funds, the cost of borrowed funds, and the size of the state subsidy. The paper contains formulas for calculating net present value, simple and discounted payback period of investments.

The above-mentioned studies do not contain an assessment of the contribution of energy tariff growth. In connection with the gradual exhaustion of sources of primary energy, despite some bursts of volatility, the cost of energy carriers has a steady rising trend. This is especially valid for developing economies, where energy tariffs are constantly increasing. In St. Petersburg, the total increase in the cost of heat energy for the period from 2006 to 2016 amounted to 224 %, reaching in some years 22.4 % per year (Table 1).

Table 1. Dynamics of thermal energy tariffs growth in St. Petersburg from 2006 to 2016 with centralized heat supply

Year	Tariff value, ruble/Gcal (VAT included)	Increase in the cost of thermal energy in absolute terms, ruble/Gcal	Increase in the cost of thermal energy in relation to the previous year, %
2006	500.40		
2007	575.46	75.06	+ 15.0
2008	650.00	74.54	+ 13.0
2009	795.73	145.73	+ 22.4
2010	931.00	135.27	+ 17.0
2011	1050.00	119.00	+ 12.8
2012	1175.00	125.00	+11.9
2013	1351.25	176.25	+15.0
2014	1408.01	56.76	+4.2
2015	1541.78	133.77	+9.5
2016	1621.95	80.17	+5.2
Average in 10 years		112.16	+12.6
Total in 10 years		1121.55	+224.1

The absence of an indicator characterizing the growth of the cost of energy resources in models leads to an overestimation of the payback period of investments in energy saving. Because of this, the investments risk increases*.* The authors propose a mathematical model of recoupment that takes into account not only the size of investments and the discount rate of future cash flows, but also the estimated value of the growth in the cost of energy carriers.

The aim of the research is to develop a mathematical model which includes a combination of technical and economic indicators influencing both the discounted cash flow value and payback period in energy saving. The objectives of the research are to define essential factors influencing the investments payback period, to derive main defining equation, to provide the analysis of this obtained equation and to examine its properties and results.

2. Methods

Criteria for assessing the effectiveness of investment were originally developed for banking and financial sectors of the economy. Gradually, they became widespread in other areas of economic activity, including construction industry and energy.

Currently, investment in energy saving is becoming actual. This type of investment is demanded by society and in many countries is supported by the governments. The development of legislation stimulates the introduction of energy service contracts.

Despite the commonness of the basic economic laws, the construction industry has its own specifics. Incomplete accounting of variables in the mathematical model of payback or inaccurate forecast of their change within the period under consideration can lead to significant loss of the funds invested in the project and failure to achieve the forecasted profit.

In Russia, payback period of investments is defined as the ratio of the initial investment's size to the value of the estimated cash flow:

$$SPP = \frac{IC_0}{CF_1}, \tag{1}$$

where IC_0 – value of the invested capital;

CF_1 – cash flow, achieved as the result of the implementation of energy saving measures and savings in operating costs, or expected to be achieved at the stage of project development after the end of the calendar year or one full heating period.

For example, if the initial investment in energy saving is € 100,000, and the income from the energy-saving activities after the end of the first calendar year or the heating season is 10,000 euros, the simple (no-discount) payback period calculated by formula (1) is 100,000 / 10 000 = 10 years.

It assumes that the cash flow in formula (1) is unchanged throughout the life cycle of the building. This approach was valid for the socialist model of the economy, when tariffs for thermal energy remained unchanged for a long period of time, and the government issued loans as interest-free subsidies.

The payback period of investments, calculated according to the formula (1), was received without taking into account:

- discounting future cash flows;
- increase in the cost (tariff) for energy carriers;
- interest on the loan (when borrowed funds are used).

For this reason, the value of a simple payback period calculated by formula (1) can only be regarded as an estimate.

Therefore the goal of further research is comprehensively taking into account the limitations of equation (1) noted above and developing a mathematical model that takes into account noted above factors.

We can account discounting future cash flows for in the following amendment as:

$$CF_n = \sum_{t=1}^{n} \frac{CF_t}{(1+i)^n}, \tag{2}$$

where t – the calculation step (year, month, etc.);

n – number of the period under consideration;

CF_t – cash flow in t years;

i – discount rate.

While estimating future cash flows to take only discounting into consideration is not enough. In this case, the size of the annual savings of funds obtained as a result of the implementation of energy-saving activities, with each subsequent year (or heating period) will increase. Therefore, each year the amount of cash flow will increase.

Let us assume that the average annual increase in tariffs for energy carriers (in relative units) is r (for example, with an annual average tariff growth of 10 %, r = 0.1). Then, the annual savings of funds for any considered year n (first: n = 1, second: n = 2, third: n = 3, etc.), achieved by the implementation of energy-saving measures, taking into account annual tariff growth can be defined by the following expression:

$$CF_t = CF_1 \cdot (1+r)^n. \tag{3}$$

The coefficient, taking into account the estimated growth dynamics in energy tariffs r in subsequent years, in this case plays the same role as the deposit rate when opening a time deposit in the bank.

In this case, equation (2) takes the form:

$$CF_n = \sum_{t=1}^{n} CF_1 \cdot \frac{(1+r)^n}{(1+i)^n}. \tag{4}$$

The exponents in the numerator and denominator of expression (4) coincide, because the time interval taken to calculate the discounted value of investments and the savings achieved as a result of the implementation of energy-saving solutions coincides.

Let us introduce the following notation:

$$q = \frac{1+r}{1+i}. \tag{5}$$

Taking into account expressions (4) and (5), the total cash flow after n years from the moment implementation of a set of energy-saving activities is:

$$CF_n = CF_1 + q \cdot CF_1 + q^2 \cdot CF_1 + \ldots + q^{n-1} \cdot CF_1. \tag{6}$$

Multiply the left and right sides of equation (6) by q. We get:

$$CF_n \cdot q = q \cdot CF_1 + q^2 \cdot CF_1 + \ldots + q^n \cdot CF_1. \tag{7}$$

We subtract from (7) the expression (6). We get:

$$(q-1) \cdot CF_n = CF_1 \cdot \left[q^n - 1\right], \tag{8}$$

from where:

$$CF_n = CF_1 \cdot \frac{(q^n - 1)}{(q-1)} = CF_1 \cdot \frac{\left(\frac{1+r}{1+i}\right)^n - 1}{(r-i)} \cdot (1+i). \tag{9}$$

Let us substitute the received expression of the total cash flow accumulated over n years of implementation of energy saving solutions into the formula for calculating net present value:

$$NPV = -IC_0 + CF_n = -IC_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+i)^n} = -IC_0 + CF_1 \cdot \frac{\left(\frac{1+r}{1+i}\right)^n - 1}{(r-i)} \cdot (1+i). \tag{10}$$

We equate the net present value to zero value:

$$NPV = -IC_0 + CF_1 \cdot \frac{\left(\frac{1+r}{1+i}\right)^n - 1}{(r-i)} \cdot (1+i) = 0. \tag{11}$$

This will allow to calculate the discounted payback period of investments into energy saving. In this case, the number of the considered period n turns out to be identical to the discounted payback period of investments.

We get:

$$\frac{IC_0}{CF_1} \cdot \frac{(r-i)}{(1+i)} + 1 = \left(\frac{1+r}{1+i}\right)^{DPP}, \tag{12}$$

whence it follows that the discounted payback period of investments is:

$$DPP = \frac{\ln\left[1 + \frac{IC_0}{CF_1} \cdot \frac{r-i}{1+i}\right]}{\ln\left[\frac{1+r}{1+i}\right]}. \tag{13}$$

The expression in the denominator of formula (13) can be transformed as follows:

$$\ln\left[\frac{1+r}{1+i}\right] = \ln\left[1 + \frac{r-i}{1+i}\right].$$

In this case, expression (13) taking into account (1) can be represented as:

$$DPP = \frac{\ln\left[1+\frac{IC_0}{CF_1}\cdot\frac{r-i}{1+i}\right]}{\ln\left[1+\frac{r-i}{1+i}\right]} = \frac{\ln\left[1+SPP\cdot\frac{r-i}{1+i}\right]}{\ln\left[1+\frac{r-i}{1+i}\right]}. \quad (14)$$

If the investor uses its own funds to accomplish the set of energy-saving activities, the calculation of the discounted payback period of investments into energy saving according to the formula (14) is final.

If the investor uses borrowed funds, the amount of investment in energy saving (with annuity monthly payments) should be calculated by the formula:

$$IC_l = m\cdot A\cdot IC_0, \quad (15)$$

where m – the number of loan installments periods (for example, if the loan is taken for 1 year: m = 12, if for 2 years: m = 24, etc.);

A – the annuity factor;

IC_0 – the same as in formula (1).

The annuity coefficient is calculated by the formula:

$$A = \frac{p_l\cdot(1+p_l)^m}{(1+p_l)^m-1}, \quad (16)$$

where p_l – the bank's interest rate on the loan;

m – the same as in formula (15).

Then the final expression for calculating the discounted payback period of investments should be given as follows:

$$DPP = \frac{\ln\left[1+\frac{IC_l}{CF_1}\cdot\frac{r-i}{1+i}\right]}{\ln\left[1+\frac{r-i}{1+i}\right]}. \quad (17)$$

Equation (14) allows to calculate the discounted payback period for investments in energy savings using the investor's own funds, equation (17) takes into account the amount of the bank loan. The amount of the loan thus increases the payback period of investments in energy saving.

The model allows to obtain the defining equation even when the investments consist of two parts: the investor's own funds and the bank loan.

3. Result and Discussion

We have obtained equations that allow calculating the discounted payback period for investments in energy saving, taking into account:

- the required investment size;
- loan repayments (if any);
- the change in the time of the cost of energy resources;
- discounting future cash flows achieved by saving money as a result of the implementation of the energy saving event or complex of activities.

As a rule, other research studies do not take into account the whole combination of the factors described above. Most of the researchers estimate the expected payback period of the investments either using simple payback period model or taking into account only discounting future cash flow.

In the most general form, the proposed mathematical model is represented by the equation (17). It allows to calculate the discounted payback period of any energy-saving measure or technical solution.

The accuracy of the mathematical model depends on the accuracy of the assessment of the energy saving potential of the planned energy-saving measure and the accuracy of the forecasted growth rates of tariffs for energy resources and discount rates.

When borrowed funds are used, we recommend to use key interest rate of the Central Bank of the country as a discount rate When one’s own funds are used while setting the value of a discount rate in formula (17) risks shall be taken into account, the numerical values of which depend on the specifics of a particular project financing.

The advantage of the presented mathematical model is that it allows to estimate the discounted payback period of investments using a single formula.

Factors that have a positive impact on reduction of the investments discounted payback period in energy saving are:

– growth of tariffs for energy carriers;

– decrease in interest rates on the loan;

– reduction of inflation and risks;

– increase of energy saving potential;

– reduction of the size of the initial investment.

Let us analyze the obtained mathematical model using the example of expression (13).

The value of the coefficient characterizing the growth dynamics of tariffs for energy resources will be taken equal to the discount rate value: $r=i$.

Under this condition, the numerator and denominator in expression (13) become equal to 0:

$$DPP=\frac{\ln\left[1+\frac{IC_0}{CF_1}\cdot\frac{r-i}{1+i}\right]}{\ln\left[\frac{1+r}{1+i}\right]}=\frac{\ln\left[1+\frac{IC_0}{CF_1}\cdot\frac{i-i}{1+i}\right]}{\ln\left[\frac{1+i}{1+i}\right]}=\frac{\ln[1]}{\ln[1]}=\frac{0}{0}. \quad (18)$$

Thus, we obtain an uncertainty of the form 0/0. We will uncover the uncertainty obtained.

We introduce an infinitesimal quantity $\varepsilon=r-i$. We expand the numerator and denominator of expression (13) in a series and leave only the first two terms of the expansion. We will receive accordingly:

$$\ln\left[1+\frac{IC_0}{CF_1}\cdot\frac{(r-i)}{(1+i)}\right]\approx\frac{IC_0}{CF_1}\cdot\frac{\varepsilon}{(1+i)}-\left(\frac{IC_0}{CF_1}\right)^2\cdot\frac{\varepsilon^2}{2(1+i)^2}; \quad (19)$$

$$\ln\left[\frac{1+r}{1+i}\right]=\ln\left[1+\frac{r-i}{1+i}\right]=\ln\left[1+\frac{\varepsilon}{1+i}\right]\approx\frac{\varepsilon}{1+i}-\frac{\varepsilon^2}{2(1+i)^2}. \quad (20)$$

We transform the expression (13) to the form:

$$DPP=\frac{IC_0}{CF_1}\left\{1+\frac{(r-i)}{2(1+i)}\left[1-\frac{IC_0}{CF_1}\right]\right\}. \quad (21)$$

The second term in the curly brackets of equation (21) gives an amendment to the evaluation of the payback period of investments.

If we assume again $r=i$ we get the following:

$$DPP = \frac{IC_0}{CF_1}\left\{1+\frac{(r-i)}{2(1+i)}\left[1-\frac{IC_0}{CF_1}\right]\right\} = \frac{IC_0}{CF_1}\{1+0\} = \frac{IC_0}{CF_1} = SPP, \tag{22}$$

Then the expression for the payback period of the investment returns to the original expression (1), which is used to calculate the simple (not discounted) payback period of investments.

A deeper analysis of the mathematical model presented above shows that:

- for $r > i$, the discounted payback period, calculated by formula (18), is less than the simple (no-discount) calculated by formula (1), i.e. $DPP < SPP$;
- for $r = i$, the discounted payback period, as was shown above, becomes equal to the simple one, i.e. $DPP = SPP$;
- for $r < i$, the discounted payback period is more simple, i.e. $DPP > SPP$.

Thus, neither the growth of tariffs for energy resources nor the discount rate independently affects the payback period of investments in energy saving.

As a result, the government can create favorable, to some extent, conditions for attracting investments in energy saving.

When comparing different options for energy-saving technical solutions, the most optimal one should be one for which the discounted payback period of investments takes the least value, i.e. the following condition is fulfilled:

$$DPP_i = \frac{\ln\left[1+\frac{IC_l}{CF_1}\cdot\frac{r-i}{1+i}\right]}{\ln\left[1+\frac{r-i}{1+i}\right]} \to \min. \tag{23}$$

It should be noted that equation (23) contains several variables with time parameters. In particular, these include:

- the parameter characterizing the dynamics of changes in tariffs for heat energy;
- the rate at which discounting of future cash flows is estimated.

For long time intervals (for example, tens of years), forecasting the dynamics of changes in these variables is a difficult task. Therefore, when predicting the discounted payback period of investments invested in energy saving, one should consider not one, but several possible scenarios of behavior of the variables in equation (23), and choose the most probable scenarios from the list of obtained results.

4. Conclusions

We developed a mathematical model for estimating the discounted payback period of investments aimed at the reduction of energy resources consumed in the building. The obtained equations allow calculating the projected payback period for investments in energy conservation, taking into account the size of the investment, the estimated or actual value of the energy saving effect achieved, the growth dynamics of energy tariffs, the discounting of future cash flows, and the amount and maturity of the loan. The proposed mathematical model allows a quick and high-quality comparison of the economic viability of various energy-saving solutions and choose the most optimal one from them.

As a result of the research it is concluded that the factors positively affecting the decrease in the discounted payback period of investments in energy saving are:

- growth of tariffs for energy carriers;
- decrease in interest rates on the loan;
- reduction of inflation and risks;
- increase in energy-saving potential of the implemented technical solution;
- reduction of the amount of the initial investment.

When determining the discounted payback period of investments in energy saving, a more accurate estimate is provided not by numerical values of the coefficient characterizing the dynamics of changes in the cost of energy resources and discount rates, but by their difference ($r-i$).

If $r=i$ the discounted payback period of investments in energy saving becomes equal to a simple payback period.

The greater the positive difference between the parameters and, entering into the defining equation, the faster the investment in energy saving pays off.

With $r<i$ the risks of non-return of investment in energy saving significantly increase.

Borrowed funds also increase the discounted payback period of investments in energy saving.

The results of the research can be used by investors to assess the effectiveness of investments in energy saving more accurate, and by public authorities - to develop a set of activities to attract investment (to stimulate energy service activities).

References

1. Korniyenko S.V., Vatin N.I., Gorshkov A.S. Thermophysical field testing of residential buildings made of autoclaved aerated concrete blocks. *Magazine of Civil Engineering.* 2016. No. 4. Pp. 10–25.
2. Gorshkov A., Vatin N., Nemova D., Shabaldin A., Melnikova L., Kirill P. Using life-cycle analysis to assess energy savings delivered by building insulation. *Procedia Engineering.* 2015. No. 1(117). Pp. 1085–1094.
3. Vatin N.I., Gorshkov A.S., Nemova D.V., Staritcyna A.A., Tarasova D.S. The energy-efficient heat insulation thickness for systems of hinged ventilated facades. *Advanced Materials Research.* 2014. No. 941–944. Pp. 905–920.
4. Fuliotto R., Cambuli F., Mandas N., Bacchin N., Manara G., Chen Q. Experimental and numerical analysis of heat transfer and airflow on an interactive building façade. *Energy and Buildings.* 2010. No. 42. Pp. 23–28.
5. Vatin N.I., Petrichenko M.R., Korniyenko S.V., Gorshkov A.S., Nemova D.V. Air mode of a triple wall. *Construction of Unique Buildings and Structures.* 2016. No. 6. Pp. 102–114. (rus)
6. Kim J.J. Economic analysis on energy saving technologies for complex manufacturing building. *Resources, Conservation and Recycling.* 2017. No. 123. Pp. 249–254.
7. Zadvinskaya T.O., Gorshkov A.S. Comprehensive method of energy efficiency of residential house. *Advanced Materials Research.* 2014. No. 953–954. Pp. 1570–1577.
8. Boait P.J., Rylatt R.M A method for fully automatic operation of domestic heating. *Energy and Buildings.* 2010. No. 42. Pp. 11–16.
9. Lauenburg P., Wollerstrand J. Adaptive control of radiator systems for a lowest possible district heating return temperature. *Energy and Buildings.* 2014. No. 11. Pp. 132–140.
10. Cheng Y., Nin J., Gao N. Thermal comfort models: a review and numerical investigation. *Building and Environment.* 2012. No. 47. Pp. 13–22.
11. Perlova E., Platonova M., Gorshkov A., Rakova X. Concept Project of Zero Energy Building. *Procedia Engineering.* 2015. No. 100. Pp. 1505–1514.
12. Rodrigues S., Voss K., Todorovich M. Energy efficiency evaluation of zero energy houses. *Energy and Buildings*. 2014. No. 83. Pp. 23–35.
13. Vasilyev G.P., Gornov V.F., Peskov N.V., Popov M.P., Kolesova M.V., Yurchenko V.A. Ground moisture phase transitions. *Magazine of Civil Engineering.* 2017. No. 6. Pp. 102–117.
14. Hewitt N.J., Huang M.J., Anderson M., Ouinn M. Advanced air source heat pumps for UK and European domestic buildings. *Applied Thermal Engineering.* 2011. No. 31.

Литература

1. Корниенко С.В., Ватин Н.И., Горшков А.С. Натурные теплофизические испытания жилых зданий из газобетонных блоков // Инженерно-строительный журнал. 2016. № 4(64). С. 10–25.
2. Gorshkov A., Vatin N., Nemova D., Shabaldin A., Melnikova L., Kirill P. Using life-cycle analysis to assess energy savings delivered by building insulation // Procedia Engineering. 2015. № 1(117). Pp. 1085–1094.
3. Vatin N.I., Gorshkov A.S., Nemova D.V., Staritcyna A.A., Tarasova D.S. The energy-efficient heat insulation thickness for systems of hinged ventilated facades // Advanced Materials Research. 2014. № 941–944. Pp. 905–920.
4. Fuliotto R., Cambuli F., Mandas N., Bacchin N., Manara G., Chen Q. Experimental and numerical analysis of heat transfer and airflow on an interactive building façade // Energy and Buildings. 2010. № 42. Pp. 23–28.
5. Ватин Н.И., Петриченко М.Р., Корниенко С.В., Горшков А.С., Немова Д.В. Воздушный режим трехслойной стеновой конструкции // Строительство уникальных зданий и сооружений. 2016. № 6. С. 102–114.
6. Kim J.J. Economic analysis on energy saving technologies for complex manufacturing building // Resources, Conservation and Recycling. 2017. № 123. Pp. 249–254.
7. Zadvinskaya T.O., Gorshkov A.S. Comprehensive method of energy efficiency of residential house // Advanced Materials Research. 2014. № 953–954. Pp. 1570–1577.
8. Boait P.J., Rylatt R.M A method for fully automatic operation of domestic heating // Energy and Buildings. 2010. № 42. Pp. 11–16.
9. Lauenburg P., Wollerstrand J. Adaptive control of radiator systems for a lowest possible district heating return temperature // Energy and Buildings. 2014. № 11. Pp. 132–140.
10. Cheng Y., Nin J., Gao N. Thermal comfort models: a review and numerical investigation // Building and Environment. 2012. № 47. Pp. 13–22.
11. Perlova E., Platonova M., Gorshkov A., Rakova X. Concept Project of Zero Energy Building // Procedia Engineering. 2015. № 100. Pp. 1505–1514.
12. Rodrigues S., Voss K., Todorovich M. Energy efficiency evaluation of zero energy houses // Energy and Buildings. 2014. № 83. Pp. 23–35.
13. Васильев Г.П., Горнов В.Ф., Песков Н.В., Попов М.И., Колесова М.В., Юрченко В.А. Фазовые переходы влаги в грунте. Учет при проектировании грунтовых теплообменников // Инженерно-строительный журнал. 2017. № 6(74). С. 102–117.
14. Hewitt N.J., Huang M.J., Anderson M., Ouinn M. Advanced air source heat pumps for UK and European domestic

Pp. 3713–3719.

15. You T., Wu W., Shi W., Wang B., Li X. An overview of the problems and solutions of soil thermal imbalance of ground-coupled heat pumps in cold regions. *Applied Energy.* 2016. No. 177. Pp. 515–536.
16. Benati S. An optimization model for stochastic project networks with cash flows. *Computational Management Science 3.* 2006. No. 4. Pp. 271–284.
17. Demeulemeester E.L., Herroelen W.S. *Project Scheduling – A Research Handbook.* Kluwer Academic Publishers. Chichester. 2005. 375 p.
18. Elmaghraby S.E. On the fallacy of averages in project risk management. *European Journal of Operational Research.* 2005. No. 165. Pp. 307–313.
19. Elmaghraby S.E., Herroelen W.S. The scheduling of activities to maximize the net present value of projects. *European Journal of Operational Research.* 1990. No. 49. Pp. 35–49.
20. Elmaghraby S.E., Kamburowski J. On project representation and activity floats. *Arabian Journal of Science and Engineering.* 1990. No. 15. Pp. 626–637.
21. Herroelen W.S., Dommelen P.V., Demeulemeester E.L. Project network models with discounted cash flows – A guided tour through recent developments. *European Journal of Operational Research.* 1997. No. 100. Pp. 97–121.
22. Herroelen W.S., Leus R. Project scheduling under uncertainty: Survey and research potentials. *European Journal of Operational Research.* 2005. No. 165. Pp. 289–306.
23. Özdamar L., Dündar H. A flexible heuristic for a multi-mode capital constrained project scheduling problem with probabilistic cash inflows. *Computers and Operations Research.* 1997. No. 24. Pp. 1187–1200.
24. Rockafellar R.T., Uryasev S. Optimization of conditional value-at-risk. *Journal of Risk.* 2000. No. 2. Pp. 21–41.
25. Stephan K., Menassa C. Modeling the Effect of Building Stakeholder Interactions on Value Perception of Sustainable Retrofits. *J. Comput. Civ.Eng.* 2014. No. 3. Pp. 68–78.
26. Breslau V., Fowles R.H. *Sustainability Perspectives and Trends in Corporate Real Estate.* Jones Lang LaSalle and CoreNet Global. London. 2007. 486 p.
27. Bond S., Mitchell P. Alpha and persistence in real estate fund performance. *J. Real Estate Finance.* 2010. No. 41. Pp. 53–79.
28. Kaplan S., Schoar A. Private equity performance: Returns, persistence, and capital flows. *J. Finance.* No. 60. Pp. 1791–1823.
29. Sharpe W. Decentralized investment management. *J. Finance.* No. 36. Pp. 217–234.
30. Gilemhanov R.A., Braila N.V. Methods of assessment of financial efficiency in construction projects. *Construction of Unique Buildings and Structures.* 2016. No. 10. Pp. 7–19. (rus)
31. Leventsov A.N., Leventsov V.A. EFFECTIVE INVESTMENTS IN MODERN. *Collection: FINANCIAL SOLUTIONS OF THE XXI CENTURY: THEORY AND PRACTICE a collection of scientific papers of the 17th International Scientific and Practical Conference.* St. Petersburg Polytechnic University of Peter the Great. 2016. Pp. 235–241. (rus)
32. Vasilyeva AG., Dzyubenko I.B., Zavadskaya V.V., et al. Financial management of the development of economic systems: monograph. Book 13. Novosibirsk: Publishing house of CRNS, 2016. 358 p. (rus)
33. De Santoli L., Fraticelli F., Fornari F., Calice C. Energy performance assessment and a retrofit strategies in public school buildings in Rome. *Energy and Buildings.* 2014. No. 68. Pp. 196–202.

buildings // Applied Thermal Engineering. 2011. № 31. Pp. 3713–3719.

15. You T., Wu W., Shi W., Wang B., Li X. An overview of the problems and solutions of soil thermal imbalance of ground-coupled heat pumps in cold regions // Applied Energy. 2016. № 177. Pp. 515–536.
16. Benati S. An optimization model for stochastic project networks with cash flows // Computational Management Science 3. 2006. № 4. Pp. 271–284.
17. Demeulemeester E.L., Herroelen W.S. Project Scheduling – A Research Handbook. Kluwer Academic Publishers. Chichester. 2005. 375 p.
18. Elmaghraby S.E. On the fallacy of averages in project risk management // European Journal of Operational Research. 2005. № 165. Pp. 307–313.
19. Elmaghraby S.E., Herroelen W.S.The scheduling of activities to maximize the net present value of projects // European Journal of Operational Research. 1990. № 49. Pp. 35–49.
20. Elmaghraby S.E., Kamburowski J. On project representation and activity floats // Arabian Journal of Science and Engineering. 1990. № 15. Pp. 626–637.
21. Herroelen W.S., Dommelen P. V., Demeulemeester E.L. Project network models with discounted cash flows – A guided tour through recent developments // European Journal of Operational Research. 1997. № 100. Pp. 97–121.
22. Herroelen W.S., Leus R. Project scheduling under uncertainty: Survey and research potentials // European Journal of Operational Research. 2005. № 165. Pp. 289–306.
23. Özdamar L., Dündar H. A flexible heuristic for a multi-mode capital constrained project scheduling problem with probabilistic cash inflows // Computers and Operations Research. 1997. № 24. Pp. 1187–1200.
24. Rockafellar R.T., Uryasev S. Optimization of conditional value-at-risk // Journal of Risk. 2000. No. 2. Pp. 21–41.
25. Stephan K., Menassa C. Modeling the effect of building stakeholder interactions on value perception of sustainable retrofits // J. Comput. Civ.Eng. 2014. № 3. Pp. 68–78.
26. Breslau B., Fowles R.H. Sustainability perspectives and trends in corporate real estate. Jones Lang LaSalle and CoreNet Global. London. 2007. 486 p.
27. Bond S., Mitchell P. Alpha and persistence in real estate fund performance // J. Real Estate Finance. 2010. № 41. Pp. 53–79.
28. Kaplan S., Schoar A. Private equity performance: Returns, persistence, and capital flows // J. Finance. № 60. Pp. 1791–1823.
29. Sharpe W. Decentralized investment management // J. Finance. № 36. Pp. 217–234.
30. Гилемханов Р.А., Брайла Н.В. Методы оценки финансово-экономической эффективности инвестиционно-строительных проектов // Строительство уникальных зданий и сооружений. 2016. № 10. С. 7–19.
31. Левенцов А.Н., Левенцов В.А. Эффективные инвестиции в современных условиях // Сборник: ФИНАСОВЫЕ РЕШЕНИЯ XXI ВЕКА: ТЕОРИЯ И ПРАКТИКА 17-й научно-практической конференции. Санкт-Петербургский политехнический университет Петра Великого. 2016. С. 235–241.
32. Васильева А.Г., Дзюбенко И.Б., Завадская В.В. и др. Финансовое управление развитием экономических систем. Книга 13. / Под общей редакцией С.С.Чернова. Изд. 2-е. Новосибирск, 2016. 358 с.
33. De Santoli, L., Fraticelli, F., Fornari, F., Calice, C. Energy performance assessment and a retrofit strategies in public school buildings in Rome // Energy and Buildings. 2014. № 68. Pp. 196–202.

34. Corrado V., Murano G., Paduos S., Riva G. On the Refurbishment of the Public Building Stock Toward the Nearly Zero-energy Target: Two Italian case studies. *Energy Procedia.* 2016. No. 101. Pp. 105–112.
35. Han X., Chen J., Huang C., Weng W., Wang L., Niu R. Energy audit and air-conditioning system renovation analysis on office buildings using air-source heat pump in Shanghai. *Building Services Engineering Research and Technology.* 2014. No. 35(4). Pp. 376–392.
36. Napoli G., Gabrielli L., Barbaro S. The efficiency of the incentives for the public buildings energy retrofit. The case of the Italian regions of the "objective convergence". *Valori e Valutazioni.* 2017. No. 18. Pp. 25–39.
37. Matic D., Calzada J.R., Eric M., Babin M. Economically feasible energy refurbishment of prefabricated building in Belgrade, Serbia. *Energy and Building.* 2014. http://dx.doi.org/10.10/j.enbuild.2014.10.041.

34. Corrado V., Murano G., Paduos S., Riva G. On the Refurbishment of the Public Building Stock Toward the Nearly Zero-energy Target: Two Italian case studies // Energy Procedia. 2016. № 101. Pp. 105–112.
35. Han X., Chen J., Huang C., Weng W., Wang L., Niu R. Energy audit and air-conditioning system renovation analysis on office buildings using air-source heat pump in Shanghai // Building Services Engineering Research and Technology. 2014. № 35(4). Pp. 376–392.
36. Napoli G., Gabrielli L., Barbaro S. The efficiency of the incentives for the public buildings energy retrofit. The case of the Italian regions of the "objective convergence" // Valori e Valutazioni. 2017. № 18. Pp. 25–39.
37. Matic D., Calzada J.R., Eric M., Babin M. Economically feasible energy refurbishment of prefabricated building in Belgrade, Serbia // Energy and Building. 2014. http://dx.doi.org/10.10/j.enbuild.2014.10.041.

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Горшков А.С., Ватин Н.И., Рымкевич П.П., Кудревич О.О. Период возврата инвестиций в энергосбережение // Инженерно-строительный журнал. 2018. № 2(78). С. 65–75.