The Complex Evaluation of Geo Eco-Protective Technologies Taking into Account the Influence of Negative Temperatures

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Abstract. The article considers the issue of integrated assessment of various geo-protective technologies that can be used in a cold region. For the first time, a parameter is introduced that takes into account the effect of negative temperature on the work of the technology being introduced as a whole. Materials for construction can also be assessed by the above algorithm. The calculation ends with a PQ index for each object.

1. Introduction
Geoprotective technologies are very diverse. Such technologies should be compared. There are many assessments and they are diverse. This estimate is called the PQ index - property quality. The PQ method is a complex evaluation of an object by its numerical evaluation. Significant properties should be selected. The PQ index results in a dimensionless number from 0 to 1. The technology comparison is based on the best index value [1-3].

Negative temperatures are frequent in the northern regions of Russia. But the influence of negative temperatures was not taken into account in the methods. The authors proposed a method of reducing the negative temperature to the range from 0 to 1. The process is called obtaining the PQ index for this property.

This algorithm makes it possible to compare different technologies in selected aspects. The selection of aspects of the comparison should be made on the basis of expert judgment. Technological aspect, operational aspect, environmental aspect can be selected as such aspects. The significance of each aspect of the comparison is also determined by peer review. The sum of all aspects of the comparison should be equal to 1 or 100%.

If various materials for the construction of transport facilities are to be selected, then compare the quality of these materials, its operational properties. Ecological properties should also be included. Accounting for the effects of negative temperatures should be taken into account when applying technology in cold regions. This influence should be involved in every aspect [4-7].

2. Experiments and results
The technological aspect usually includes the quality parameters of the material. The main properties of lightweight concrete on porous aggregates are density, thermal conductivity, strength and frost resistance. Frost resistance is necessarily taken into account. Cold resistance of materials is important when operating in cold regions. The strength of materials is also included in the technological aspect.
These properties of the technological aspect should be selected on the basis of expert judgment as well.

The operational aspect includes those properties that are important in the operation of transport facilities. Noise protection will be important when installing noise protection screens. The thermal conductivity of materials must be taken into account. The thickness of the walls will be important when building structures. Vapor permeability will also be important. When operating in negative temperature conditions, it is important that the material is not hygroscopic. Water absorption of the material is also important. Sound insulation capacity for materials can also be considered if necessary. Special operating conditions require special properties for this aspect. For example, the chemical resistance of materials, the corrosion resistance of materials can be chosen [8-11].

Nature is very slowly recovering in cold regions. The environmental aspect is also very important. Materials must be inert to the environment. Negative impact should not be. The possibility of using materials after the life cycle can also be taken into account in this aspect. The term of use of the material ends. And then we can take into account what happens next with this material. Well, when the material can be used later in another quality. Some waste of foam concrete and ash foam concrete can be used in geo-protection. For example, as a mineral geo-antidotes for cleaning stormwater runoff from heavy metal ions. Storm drains are generated at the facilities of the linear transport infrastructure. Such reuse of materials can generate revenue. It is bad when the material can not be used further. It must be unstructured. This is an additional expense [12-14].

The general algorithm for the formation of the PQ index of an object for several properties is shown in figure 1.

1. The choice of objects of study
2. Selection of aspects of the comparison of objects of study
   Determining the significance of aspects.
3. Selecting a list of properties for each aspect of the comparison of research objects.
   Determination of the significance of the properties of each aspect.
4. Determination of the PQ index of each considered property of a certain aspect for each object.
5. Calculate the PQ index for each aspect of the comparison of study objects.
   \[ PQ_{aspects} = \sum Z_{properties} \times PQ_{properties} \]
6. Calculation of the index PQ for each selected object of study.
   \[ PQ_{object} = \sum Z_{aspects} \times PQ_{aspects} \]
7. Analysis of selected study objects based on a comparison of their PQ indices.
8. Conclusions about the feasibility of using these technologies, taking into account the influence of negative temperatures.

**Figure 1.** The general algorithm for the formation of the PQ object index.

Different technologies can be selected as objects of study. Materials for construction can also be assessed by the above algorithm. The calculation ends with a PQ index for each object. The result obtained is always in the range from 0 to 1. In this case, 1 corresponds to the case when the values of all properties of the object coincide with the best, and 0 - the values of each property coincide with the
worst values from the studied range. The higher the PQ index, the better this technology within the selected aspects [15-17].

The PQ index takes into account the intervals for each selected property. These intervals are set. The boundaries of the intervals can be set different. The rationality of better and worse values is important. The best value is selected from the expected most often. The worst value may correspond to the minimum or maximum allowed for this technology.

The algorithm for determining the PQ index of each of the considered properties of a certain aspect for each object (position 4 of figure 1) is shown in figure 2. The algorithm is shown for the case of a linear distribution.

1. Definition for each property of the interval of values, the best and the worst values in the specified interval.
2. Calculation of the coefficient of normalization interval $K_d = 1/(B-A)$.
3. Construction of the calculated schedule of quality drop.
4. Processing of experimental data, the calculation of the average value.
5. Getting the PQ index value for a specific property.

**Figure 2. PQ index calculation by property.**

The property value interval must be selected. The best interval value should be determined. The worst interval value must be determined. A value of 1 is assigned to the best value. A value of 0 is assigned to the worst value. The present value belongs to the range $0 < x < 1$. This range from 0 to 1 is called the PQ index range, and the corresponding value, the property index, is called the PQ property.

To determine this value is built function. Linear function is the easiest option. The function can be in two options:

a) the best value of the property is on the left of the interval (the smaller the value of the property, the better the property);

b) the best value of the property is on the right of the interval (the higher the value of the property, the better the property).

The functions are shown in figure 3 in a graphic image. The movement of the function from the best value to the worst is called the decline in the quality of this function. These graphs are called - the calculated schedule of quality decline. If the best property value is on the left of the specified interval, and the worst property value is on the right of the specified interval, the PQ index of this property will decrease as the property value increases from $A$ to $B$. In case the best property value is on the right of the specified interval, and the worst property value is on the left of the specified interval, the PQ index of this property will increase with increasing property value in the interval from $A$ to $B$. 
a) the best property value is on the left of the interval.

b) the best value of the property is on the right of the interval.

Figure 3. View of the quality degradation functions in a graphic image.

\[ PQ_x = 1 - (x - A) \cdot \frac{1}{B - A} \]

\[ PQ_x = 1 - (B - x) \cdot \frac{1}{B - A} \]

The angle of inclination is in this linear function. The angle of inclination or coefficient of normalization of the interval \( C_d \) is considered as a unit divided by the length of the interval, \( K_d = 1/(B - A) \). If the property changes irregularly over the interval, then the interval should be divided into ranges. The function must be built for each range separately. The slope of the function line is determined using the property quality drop ratio [18-20].

The value of the PQ index for a particular property can be obtained according to the schedule (figure 3) or by calculation using the formula.

A) the best value of the property coincides with the left border of the interval of properties (the smallest value of the interval is the best):

\[ PQ_x = 1 - (X - A) \times K_d \]

This option is applicable for properties such as thermal conductivity. The lower the thermal conductivity, the better for this material. This property should be considered in cases where the value of the coefficient of thermal conductivity is very important to take into account when calculating.

B) the best value of the property coincides with the right border of the interval of properties (the greatest value of the interval is the best):

\[ PQ_x = 1 - (B - X) \times K_d \]

This option is applicable for properties such as material strength. The greater the strength, the better for this material. This property should be considered in cases where the value of strength is very important to consider.

Let us show an example of comparing ash-based concrete of the same density, but with different ash content from incineration of sewage sludge. The parameters of the considered materials are given in table 1.
Table 1. Properties of ash-foam autoclaved concrete.

| Average density of foam concrete | Thermal conductivity | Compressive strength | Frost resistance, cycles | Sorption moisture% | Soundproofing ability | Sorption capacity for lead ions, mg/г |
|---------------------------------|----------------------|---------------------|------------------------|-------------------|----------------------|----------------------------------------|
| Д500 с 25% ashes                | 0,11                 | 16,5                | 15                     | 12                | 40,0                 | 22,5                                   |
| Д500 с 50% ashes                | 0,10                 | 15,0                | 15                     | 14                | 40,4                 | 22,7                                   |
| Д500 с 100% ashes               | 0,09                 | 10,5                | 10                     | 15                | 41,1                 | 23,0                                   |

The first version of the calculation: ash foam concrete is used as an internal heat insulating and soundproofing layer. The second version of the calculation: ash-foam concrete is used as an external noise shield.

Step 1. Select the objects of study.

The objects of research were selected ash foam concrete of the same density, but with different ash content from burning sewage sludge in its composition. Object number 1 - ash foam concrete containing 25% ash instead of sand. Object number 2 - ash foam concrete containing 50% ash instead of sand. Object number 3 - ash foam concrete containing ash instead of sand.

Step 2. Selection of aspects of the comparison of research objects. Determining the significance of aspects.

Aspects are taken as follows: technological, operational and environmental. Operation of the selected objects of study occurs in the absence of the influence of negative temperatures.

The significance of the aspects of the study Zj is taken equal:

- Z tech. = 30% for the technological aspect
- Z ekpl. = 50% for operational aspect
- Z ec. = 20% for the environmental aspect

Z tech. + Z ekpl + Z ecol. = 30% + 50% + 20% = 100%

Step 3. Select the list of properties for each aspect of the comparison of the objects of study. Determination of the significance of the properties of each aspect.

For the technological aspect, the following properties are selected: frost resistance, strength, density.

The significance of the properties in this technological aspect is assumed to be:

- Z frost resistance = 35% for the Frost resistance property
- Z durability = 50% for the "Strength" property
- Z density = 15% for the property "Density"

For the operational aspect, the following properties were chosen: sound insulation capacity (with a thickness of 200 mm), thermal conductivity, sorption moisture.

The significance of the properties in this operational aspect is assumed to be:

- Z Sound = 40% for the property "Sound insulation"
- Z thermal conductivity = 40% for the property "thermal conductivity"
- Zorb. vlazhnost = 20% for the property "Sorption moisture"

Zstar + Z thermal conductivity + Z adsorb. Humidity = 40% + 40% + 20% = 100%
For the environmental aspect, the following properties are selected: utilization (useful use after the life cycle), the possibility of using the material after the life cycle as mineral geo-antidotes (using the sorption capacity for lead ions as an example).

The significance of properties in this environmental aspect is assumed to be:
- $Z_{\text{utilization}} = 50\%$ for the property "Recycling"
- $Z_{\text{MGA}} = 50\%$ for the property "Thermal Conductivity"
- $Z_{\text{utilization}} + Z_{\text{MHa}} = 50\% + 50\% = 100\%$

Step 4. Determination of the PQ index of each considered property of the j-th aspect for each object.

1) Determination for each property of the interval of values, the best and the worst values in a given interval.
2) Calculation of the coefficient of normalization interval

### Table 2. The results of the calculation of intervals.

| №  | properties                        | unit measurements | min  | max  | best value | Kd     |
|----|----------------------------------|-------------------|------|------|------------|--------|
| I  | TECHNOLOGICAL ASPECT            |                   |      |      |            |        |
| 1  | frost resistance                 | cycle             | 5    | 25   | 25         | 0,0500 |
| 2  | strength                         | Mpa               | 10   | 20   | 20         | 0,1000 |
| 3  | density                          | kg /m$^3$         | 400  | 800  | 400        | 0,0025 |
| II | OPERATIONAL ASPECT              |                   |      |      |            |        |
| 1  | sound insulation capacity        | Mpa               | 38   | 42   | 42         | 0,2500 |
| 2  | thermal conductivity             | Vт/м$^2$×°С       | 0,090| 0,130| 0,090      | 25,000 |
| 3  | sorption humidity                | %                 | 10,0 | 16,0 | 10,0       | 0,1667 |
| II | ENVIRONMENTAL ASPECT             |                   |      |      |            |        |
| I  | I                               |                   |      |      |            |        |
| 1  | recycling                        | 1 - yes           | 0    | 1    | 1          | 1,0000 |
| 2  | leadion sorption capacity        | mg/r              | 0    | 30   | 30         | 0,0333 |

3) Construction of the calculated schedule of quality decline.

From table 2, we can conclude that the indicators of properties on density, thermal conductivity, sorption humidity correspond to the schedule 3a). Indicators of frost resistance, strength, sound insulation capacity, utilization and sorption capacity correspond to the schedule 3b).

4) Processing of experimental data, the calculation of the average value.

The data presented in table 1.

5) Getting the value of the PQ index for a specific property.
Table 3. The results of the calculation of the indices PQ properties.

| № | properties                  | ash foam concrete 25 | ash foam concrete 50 | ash foam concrete 100 |
|---|------------------------------|----------------------|----------------------|-----------------------|
|   |                              | unit. Measur. | PQ       | unit. Measur. | PQ       | unit. Measur. | PQ       |
| I | TECHNOLOGICAL ASPECT        | 15          | 0,500    | 15          | 0,500    | 10          | 0,250    |
| 1 | frost resistance            | 16,5        | 0,650    | 15,0        | 0,500    | 10,5        | 0,050    |
| 2 | strength                    | 500         | 0,750    | 500         | 0,750    | 500         | 0,750    |
| 3 | density                     | 40,0        | 0,500    | 40,4        | 0,600    | 41,1        | 0,775    |
| II| OPERATIONAL ASPECT         | 0,110       | 0,500    | 0,100       | 0,750    | 0,090       | 1,000    |
| 1 | sound insulation capacity    | 12,0        | 0,667    | 14,0        | 0,333    | 15,0        | 0,167    |
| 2 | thermal conductivity        | 22,5        | 0,750    | 22,7        | 0,757    | 23,0        | 0,767    |
| 3 | sorption humidity           | 22,5        | 0,750    | 22,7        | 0,757    | 23,0        | 0,767    |
| III| ENVIRONMENTAL ASPECT     |                          |           |             |           |             |           |
| 1 | recycling                   | 1           | 1,000    | 1           | 1,000    | 1           | 1,000    |
| 2 | lead ion sorption capacity  | 22,5        | 0,750    | 22,7        | 0,757    | 23,0        | 0,767    |

Step 5. Calculate the PQ index for each aspect of the comparison of study objects.

\[ PQ_{aspect} = \sum Z_{\text{properties}} \times PQ_{\text{properties}} \]

Step 6. Calculation of the index PQ for each selected object of study.

\[ PQ_{\text{object}} = \sum Z_{\text{aspect}} \times PQ_{\text{aspect}} \]

Step 7. Analysis of the selected objects of study based on a comparison of their PQ indices. Conclusions about the appropriateness of the use of these materials.

3. Conclusions

The complex evaluation of geo eco-protective technologies taking into account the influence of negative temperatures.

For the first time, a parameter is introduced that takes into account the effect of negative temperature on the work of the technology being introduced as a whole.

Waste of foam concrete and ashes of foam concrete can be used in geo-protection, for example, as mineral geo-antidotes for cleaning storm drains from heavy metal ions.

It can be concluded that in the case where the ash foam concrete is used as an internal heat insulating and soundproof layer, then ash foam concrete containing 50% ash instead of sand is preferred.

Materials for construction can also be assessed by the above algorithm. The calculation ends with a PQ index for each object.

References

[1] Batool F, Rafi M M and Bindiganavile V 2018 Microstructure and thermal conductivity of cement-based foam: A review: Journal of Building Engineering 20 pp 696-704
[2] Baydarashvili M Criteria Of Geocorptection In Construction 2017: Proceedings of the International (Scientific Conference Transportation Geotechnics and Geocology) 189 pp 616-621
[3] Cui Y and Wang D M 2019 Effects of Water on Pore Structure and Thermal Conductivity of Fly Ash-Based Foam Geopolymers: Advances in Materials Science and Engineering p 209
[4] Mohamad N and Samad M T and Lakhiar M A and Mydin S and Jusoh A and Sofia S A 2018 Effects of Incorporating Banana Skin Powder (BSP) and Palm Oil Fuel Ash (POFA) on Me-
Mechanical Properties of Lightweight Foamed Concrete: *International Journal of Integrated Engineering* **10** pp 169-176

[5] Romero A R and Salvo M and Bernardo E 2018 Up-cycling of vitrified bottom ash from MSWI into glass-ceramic foams by means of ‘inorganic gel casting’ and sinter-crystallization *Construction and Building Materials* **192** pp 133-140

[6] Shao N N and Zhang Y B and Liu D M and Wang Z and Zhang T 2018 Fabrication of hollow microspheres filled fly ash based foam geopolymers with ultra-low thermal conductivity and relative high strength *Construction and Building Materials* **185** pp 567-573

[7] Sun C and Y Zhu and J Guo and Y M Zhang and Sun X 2018 Effects of foaming agent type on the workability drying shrinkage frost resistance and pore distribution of foamed concrete *Construction and Building Materials* **186** pp 833-839

[8] Tkach E and Rakhimov A 2018 Porous fillers for light concrete from technogenic raw materials *XXI International Scientific Conference on Advanced in Civil Engineering Construction - the Formation of Living Environment IOP Conference Series-Materials Science and Engineering* **365** pp 365

[9] Xu F and G H Gu and W Zhang and H Wang M and X Huang M and Zhu J 2018 Pore structure analysis and properties evaluations of fly ash-based geopolymer foams by chemical foaming method *Ceramics International* **44** pp 19989-19997

[10] Xuan D X and Tang P and Poon C S 2019 MSWIBA-based cellular alkali-activated concrete incorporating waste glass powder *Cement Concrete Composites* **95** pp 128-136

[11] Svatovskaya L B and Kabanov A A and Sychov M M 2017 Lithosynthesis of the properties in the transport construction on the cement base *IOP Conference Series Earth and Environmental Science* **90** pp 1755-1315

[12] Svatovskaya L B and Kabanov A A and Sychov M M 2017 Soling Aerating and Phosphating for Soil Strengthening and Detoxication *Procedia Engineering* **189** pp 398-403

[13] Sychova A M and Svatovskaya L B and Mjakin S V and Vasiljeva I V 2009 Modification of fillers for cements *Electron Beam Modification of Solids Mechanisms Common Features and Promising Applications* pp 35-37

[14] Komokhov P G and Maslennikova L L and Makhmud A 2003 Control of strength of ceramic materials by forming the contact zone between clay matrix and leaning agent *Stroitel'nye Materialy* **12** pp 44-46

[15] Maslennikova L L and Abu-Khasan M S and Babak N A 2017 The use of oil-contaminated crushed stone screenings in construction ceramics *Procedia Engineering* **189** pp 59-64

[16] Abu-Khasan M and Solovyova V and Solovyov D 2018 High-strength Concrete with new organic mineral complex admixture *MATEC Web of Conferences Proceeding* **193** p 03019

[17] Sakharova A and Baidarashvili M and Petriaev A 2017 Transportation Structures and Constructions with Geoeocoprotecive Properties *Procedia engineering* **189** pp 569-575

[18] Malchevskaya K and Sakharova A and Kabanov A 2017 Soil Reinforcement and Detoxification by Means of Mineral Binder Systems *Procedia Engineering* **189** pp 582-586

[19] Baidarashvili M and Sakharova A and Petriaev A 2017 The Modern Structure for Storm Sewage Purification of Roads *Procedia Engineering* **189** pp 576-581

[20] Sakharova A and Svatovskaya L and Baidarashvili and M Petriaev A 2016 Sustainable Development in Transport Construction through the use of the Geoeocoprotecive Technologies *Procedia Engineering* **143** pp 1401-1408