Multi-factor analysis of technological operations of extinguishing exterior walls with a heat-insulating layer from concrete of low heat conductivity

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Abstract. Improving the manufacturability of the construction of external walls in monolithic housing construction is achieved due to new structural and technological solutions. The main advantages of the technology of erecting monolithic external walls using concrete with low thermal conductivity in the heat-insulating layer are the reduction of the organizational and technological stages of erecting the external walls with the elimination of the technological gap between the stages, the absence of the need to attract specialized performers to erect the heat-insulating and enclosing layers of the wall, eliminating additional installation work and dismantling scaffolding during the construction of the facade, as well as reducing the number of manual processes and the nomenclature of building materials and products, the use of which is limited by the seasonality of work or requires additional costs to ensure their design physical and technical characteristics. To assess the significance of factors, a multivariate analysis technique was used.

1. Introduction

For prevention emergency and dilapidated condition during the operation of buildings and structures associated with the laws of the physical and moral deterioration processes, planned measures are taken to overhaul the common property of multi-unit residential buildings, aimed at high improving the state of the housing stock.

Repair and construction production has a variety of the specific features, which significantly distinguished it from construction. Repair and construction work, as a rule, is carried out in extremely cramped conditions, which determines the specific technology and organization of their implementation, the use of special equipment, mechanisms, tools, devices.

One of the important directions for improving the forms and methods of organizing the overhaul of residential buildings is the creation of an integrated production preparation system based on the wide practical use of modern methods for solving organizational and technological problems.
2. Materials and Methods

The selection of factors for constructing the model was carried out on the basis of a comprehensive analysis of the complex technological process of erecting exterior walls with a heat-insulating layer of concrete with low thermal conductivity, which established that specific factors can influence the resulting indicator of the duration of building exterior walls with a heat-insulating layer of concrete of low thermal conductivity (Z). These include:

- $x_1$ - the duration of the process for installing a reinforcing cage;
- $x_2$ - the duration of the process for installing a fixed formwork slab;
- $x_3$ - the duration of the technological process for the installation of panels of inventory formwork;
- $x_4$ - the duration of the process for installing struts and scaffolds;
- $x_5$ - the duration of the technological process for fixing and alignment of the formwork;
- $x_6$ - the duration of the process for laying polystyrene concrete;
- $x_7$ - the duration of the process for compaction of polystyrene concrete;
- $x_8$ - the duration of the process for laying structural concrete;
- $x_9$ - the duration of the process of compaction of structural concrete;
- $x_{10}$ - the duration of the process to remove scaffolds, slopes;
- $x_{11}$ - the duration of the technological process for the exposure of concrete and the dismantling of panels of inventory formwork.

The combination of these factors was used to build the model and multivariate analysis, which allows to assess the significance of factors. To assess the significance of factors in the general equation, a multivariate analysis technique was used.

The main goal of multiple regression is to build a model with a large number of factors, while determining the influence of each of them individually, as well as their combined effect on the modeled indicator. The methods developed by well-known scientists make it possible to certify of the initial information [1-9]. Many similar technical solutions in the construction also developed by scientists [10-21].

The solution of the tasks posed covers two circles of questions: the selection of factors and the choice of the type of regression equation. The initial data for the correlation analysis are presented in table 1.

| Experiment number | Duration of process | Installation of reinforcing cage | Installation of fixed formwork slab | Installation of formwork shields | Installation of struts and scaffolds | Fixing and alignment of formwork | Polystyrene concrete laying | Polystyrene concrete pacKorol | Laying of structural concrete | pacKorol of structural concrete | Removing concrete scaffolds | Concrete bearing support | Concrete demounting and dismantling |
|-------------------|---------------------|---------------------------------|-----------------------------------|---------------------------------|------------------------------------|-------------------------------|---------------------------|-----------------------------|-----------------------------|-------------------------------|--------------------------|-----------------------------|--------------------------------|
| №1               | 8,70                | 1,28                            | 0,54                              | 0,35                            | 0,30                               | 0,33                          | 0,21                      | 0,20                        | 2,35                        | 0,19                          | 0,41                     | 2,54                        |
| №2               | 8,92                | 1,28                            | 0,59                              | 0,37                            | 0,38                               | 0,35                          | 0,18                      | 0,22                        | 2,38                        | 0,20                          | 0,42                     | 2,55                        |
| №3               | 8,93                | 1,29                            | 0,57                              | 0,39                            | 0,39                               | 0,34                          | 0,22                      | 0,19                        | 2,36                        | 0,19                          | 0,45                     | 2,54                        |
| №4               | 8,96                | 1,30                            | 0,59                              | 0,4                             | 0,38                               | 0,36                          | 0,19                      | 0,21                        | 2,35                        | 0,19                          | 0,40                     | 2,59                        |
| №5               | 8,82                | 1,29                            | 0,58                              | 0,36                            | 0,31                               | 0,37                          | 0,22                      | 0,18                        | 2,34                        | 0,22                          | 0,42                     | 2,53                        |
| №6               | 8,92                | 1,27                            | 0,57                              | 0,37                            | 0,38                               | 0,33                          | 0,2                       | 0,19                        | 2,39                        | 0,19                          | 0,45                     | 2,58                        |

Table 1. The initial data for the correlation analysis.
The above factors correspond to the conditions of inclusion in the general model, since all of them are quantitatively measurable. During the study, factors were checked for intercorrelation and the presence of a functional measure. [16-18] To analyze the correlation coefficients between the factors, the tool of the Data Analysis package CORRELATION (Microsoft Excel) was used. The calculation results are summarized in table 2.

Table 2. The analysis of data correlation.

| Z     | X1   | X2   | X3   | X4   | X5   | X6   | X7   | X8   | X9   | X10  | X11  |
|-------|------|------|------|------|------|------|------|------|------|------|------|
| Z     | 1    |      |      |      |      |      |      |      |      |      |      |
| X1    | 0.49 | 1.00 |      |      |      |      |      |      |      |      |      |
| X2    | 0.42 | -0.23| 1.00 |      |      |      |      |      |      |      |      |
| X3    | 0.17 | 0.35 | -0.28| 1.00 |      |      |      |      |      |      |      |
| X4    | 0.89 | 0.55 | 0.19 | 0.28 | 1.00 |      |      |      |      |      |      |
| X5    | 0.43 | 0.29 | 0.25 | -0.42| 0.23 | 1.00 |      |      |      |      |      |
| X6    | -0.15| 0.01 | -0.32| 0.01 | -0.32| -0.01| 1.00 |      |      |      |      |
| X7    | -0.01| 0.09 | -0.06| 0.11 | 0.14 | 0.09 | -0.37| 1.00 |      |      |      |
| X8    | 0.57 | 0.11 | -0.02| 0.07 | 0.46 | 0.07 | 0.01 | -0.07| 1.00 |      |      |
| X9    | -0.10| -0.47| 0.66 | -0.54| -0.40| 0.06 | 0.12 | -0.47| -0.12| 1.00 |      |
| X10   | 0.43 | 0.02 | 0.13 | -0.14| 0.52 | 0.14 | -0.08| -0.45| 0.25 | 0.06 | 1.00 |
| X11   | 0.64 | 0.10 | 0.42 | -0.10| 0.50 | 0.20 | -0.32| -0.03| 0.42 | 0.02 | 0.05| 1.00 |

Analysis of the data in table 2 shows that the closest correlation z with factors such as X1, X2, X4, X5, X8, X10, X11 while weak with X3, X6, X7, X9. Accordingly, these factors are excluded from the general model. Consider four possible combinations of factors:

- 1st option: factors X1, X2, X4, X5, X8, X10, X11 (Table 3).
- 2nd option: factors X2, X4, X5, X8, X10, X11 (Table 4).
- 3rd option: factors X1, X2, X5, X8, X10, X11 (Table 5).
Table 3. The analysis of data correlation, 1st option.

| №   | Experiment number (capture of process) | Duration of process | Installation of reinforcing cage | Installation of fixed formwork slab | Installation of struts and scaffolds | Fixing and alignment of formwork | Laying of structural concrete | Removing concrete scaffolds | Concrete bearing support | Concrete demounting and dismantling |
|-----|---------------------------------------|---------------------|----------------------------------|-------------------------------------|-------------------------------------|---------------------------------|--------------------------------|--------------------------|---------------------------|--------------------------------------|
| 1   | №1                                   | 8,70                | 1,28                             | 0,54                                | 0,3                                 | 0,33                            | 2,35                           | 0,41                     | 2,54                      |                                      |
| 2   | №2                                   | 8,92                | 1,28                             | 0,59                                | 0,38                                | 0,35                            | 2,38                           | 0,42                     | 2,55                      |                                      |
| 3   | №3                                   | 8,93                | 1,29                             | 0,57                                | 0,39                                | 0,34                            | 2,36                           | 0,45                     | 2,54                      |                                      |
| 4   | №4                                   | 8,96                | 1,30                             | 0,59                                | 0,38                                | 0,36                            | 2,35                           | 0,4                      | 2,59                      |                                      |
| 5   | №5                                   | 8,82                | 1,29                             | 0,58                                | 0,31                                | 0,37                            | 2,34                           | 0,42                     | 2,53                      |                                      |
| 6   | №6                                   | 8,92                | 1,27                             | 0,57                                | 0,38                                | 0,33                            | 2,39                           | 0,45                     | 2,58                      |                                      |
| 7   | №7                                   | 8,86                | 1,31                             | 0,56                                | 0,39                                | 0,35                            | 2,34                           | 0,43                     | 2,56                      |                                      |
| 8   | №8                                   | 8,98                | 1,30                             | 0,57                                | 0,4                                 | 0,38                            | 2,37                           | 0,43                     | 2,57                      |                                      |
| 9   | №9                                   | 8,98                | 1,30                             | 0,58                                | 0,39                                | 0,37                            | 2,39                           | 0,44                     | 2,60                      |                                      |
| 10  | №10                                  | 8,93                | 1,31                             | 0,53                                | 0,4                                 | 0,34                            | 2,38                           | 0,43                     | 2,54                      |                                      |
| 11  | №11                                  | 8,95                | 1,28                             | 0,57                                | 0,38                                | 0,38                            | 2,37                           | 0,42                     | 2,60                      |                                      |
| 12  | №12                                  | 9,06                | 1,31                             | 0,57                                | 0,41                                | 0,39                            | 2,40                           | 0,45                     | 2,58                      |                                      |
| 13  | №13                                  | 8,99                | 1,32                             | 0,56                                | 0,4                                 | 0,35                            | 2,38                           | 0,41                     | 2,59                      |                                      |
| 14  | №14                                  | 9,00                | 1,30                             | 0,58                                | 0,42                                | 0,38                            | 2,35                           | 0,47                     | 2,57                      |                                      |
| 15  | №15                                  | 8,99                | 1,29                             | 0,59                                | 0,4                                 | 0,32                            | 2,37                           | 0,44                     | 2,60                      |                                      |
|     |                                       |                     | 0,3424                           | 0,175783                            | 1,27554                            | 0,56487                         | 1,29669                        | 1,55691                  | 1,16925                   | 1,851539                              |
|     |                                       |                     | 0,41889                          | 0,533017                            | 0,46346                            | 0,37340                         | 0,45007                        | 0,53412                  | 0,72974                   | 1,871119                              |
|     | Coefficient of determination          |                     | 0,9552                           | 0,026517                            | -                                  | -                               | -                              | -                        | -                        | -                                    |
|     | Fisher's coefficient                 |                     | 21,3561                          | 7                                   | -                                  | -                               | -                              | -                        | -                        | -                                    |
|     |                                         |                     | 0,10511                          | 0,004922                            | -                                  | -                               | -                              | -                        | -                        | -                                    |
### Table 4. The analysis of data correlation, 2nd option.

| №  | Experiment number (capture of process) | 2nd option          |  |  |  |  |
|----|--------------------------------------|---------------------|---|---|---|---|
| №1 |                                      | z                   | X₂ | X₄ | X₅ | X₈ |
| 1  | №1                                  | 8,70                | 0,54 | 0,3 | 0,33 | 2,35 | 0,41 | 2,54 |
| 2  | №2                                  | 8,92                | 0,59 | 0,38 | 0,35 | 2,38 | 0,42 | 2,55 |
| 3  | №3                                  | 8,93                | 0,57 | 0,39 | 0,34 | 2,36 | 0,45 | 2,54 |
| 4  | №4                                  | 8,96                | 0,59 | 0,38 | 0,36 | 2,35 | 0,4  | 2,59 |
| 5  | №5                                  | 8,82                | 0,58 | 0,31 | 0,37 | 2,34 | 0,42 | 2,53 |
| 6  | №6                                  | 8,92                | 0,57 | 0,38 | 0,33 | 2,39 | 0,45 | 2,58 |
| 7  | №7                                  | 8,86                | 0,56 | 0,39 | 0,35 | 2,34 | 0,43 | 2,56 |
| 8  | №8                                  | 8,98                | 0,57 | 0,4  | 0,38 | 2,37 | 0,43 | 2,57 |
| 9  | №9                                  | 8,98                | 0,58 | 0,39 | 0,37 | 2,39 | 0,44 | 2,60 |
| 10 | №10                                 | 8,93                | 0,53 | 0,4  | 0,34 | 2,38 | 0,43 | 2,54 |
| 11 | №11                                 | 8,95                | 0,57 | 0,38 | 0,38 | 2,37 | 0,42 | 2,60 |
| 12 | №12                                 | 9,06                | 0,57 | 0,41 | 0,39 | 2,40 | 0,45 | 2,58 |
| 13 | №13                                 | 8,99                | 0,56 | 0,4  | 0,35 | 2,38 | 0,41 | 2,59 |
| 14 | №14                                 | 9,00                | 0,58 | 0,42 | 0,38 | 2,35 | 0,47 | 2,57 |
| 15 | №15                                 | 8,99                | 0,59 | 0,4  | 0,32 | 2,37 | 0,44 | 2,60 |
|    |                                      | 0,195782            | -0,22491 | 1,115212 | 0,795318 | 1,820343 | 1,18871 |
|    |                                      | 0,447035            | 0,514762 | 0,494884 | 0,37684 | 0,338418 | 0,527283 |
|    |                                      | Coefficient of      | determination | - | - | - | - |
|    |                                      | Fisher's           | coefficient | 0,938864 | 0,028999 | - | - | - |
|    |                                      | 20,47604           | 8 | - | - | - | - |
|    |                                      | 0,103313            | 0,006727 |
### Table 5. The analysis of data correlation, 3rd option.

| №  | Experiment number (capture of process) | Z   | X<sub>1</sub> | X<sub>2</sub> | X<sub>3</sub> | X<sub>4</sub> | X<sub>5</sub> | X<sub>6</sub> | X<sub>7</sub> | X<sub>8</sub> | X<sub>9</sub> | X<sub>10</sub> | X<sub>11</sub> |
|----|--------------------------------------|-----|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1  | №1                                  | 8.70| 1.28        | 0.54        | 0.33        | 2.35        | 0.41        | 2.54        |
| 2  | №2                                  | 8.92| 1.28        | 0.59        | 0.35        | 2.38        | 0.42        | 2.55        |
| 3  | №3                                  | 8.93| 1.29        | 0.57        | 0.34        | 2.36        | 0.45        | 2.54        |
| 4  | №4                                  | 8.96| 1.30        | 0.59        | 0.36        | 2.35        | 0.4        | 2.59        |
| 5  | №5                                  | 8.82| 1.29        | 0.58        | 0.37        | 2.34        | 0.42        | 2.53        |
| 6  | №6                                  | 8.92| 1.27        | 0.57        | 0.33        | 2.39        | 0.45        | 2.58        |
| 7  | №7                                  | 8.86| 1.31        | 0.56        | 0.35        | 2.34        | 0.43        | 2.56        |
| 8  | №8                                  | 8.98| 1.30        | 0.57        | 0.38        | 2.37        | 0.43        | 2.57        |
| 9  | №9                                  | 8.98| 1.30        | 0.58        | 0.37        | 2.39        | 0.44        | 2.60        |
| 10 | №10                                 | 8.93| 1.31        | 0.53        | 0.34        | 2.38        | 0.43        | 2.54        |
| 11 | №11                                 | 8.95| 1.28        | 0.57        | 0.38        | 2.37        | 0.42        | 2.60        |
| 12 | №12                                 | 9.06| 1.31        | 0.57        | 0.39        | 2.40        | 0.45        | 2.58        |
| 13 | №13                                 | 8.99| 1.32        | 0.56        | 0.35        | 2.38        | 0.41        | 2.59        |
| 14 | №14                                 | 9.00| 1.30        | 0.58        | 0.38        | 2.35        | 0.47        | 2.57        |
| 15 | №15                                 | 8.99| 1.29        | 0.59        | 0.32        | 2.37        | 0.44        | 2.60        |

Coeficient of determination: 0.90223, Fisher's coefficient: 12.30407, 0.099281

3. Results and discussion

As a result, 3 combinations with one or another set of factors were considered in accordance with table 6.

The quality of the model [16] is checked using three formal criteria: the coefficient of determination, the Fisher criterion, and the student criterion. In Microsoft Excel, these coefficients are calculated using the built-in LINE function. The calculation results for 3 options are shown in table 6.
As a result of the regression analysis (Table 6) in combination 1, we obtain the corresponding values of the coefficient estimates: $\beta_{2x1} = 1.17$, $\beta_{3x2} = 1.56$, $\beta_{4x4} = 1.30$, $\beta_{5x5} = 0.56$, $\beta_{6x8} = 1.28$, $\beta_{7x10} = 0.18$, $\beta_{8x11} = 0.34$.

Thus, the model can be represented by an equation of the form:

$$z' = 1.85 + 1.17 \cdot x_1 + 1.56 \cdot x_2 + 1.3 \cdot x_4 + 0.56 \cdot x_5 + 1.28 \cdot x_8 + 0.18 \cdot x_{10} + 0.34 \cdot x_{11}.$$ 

Similarly, in combination 2, we obtain the corresponding values of the coefficient estimates:

$$\beta_{3x4} = 1.82, \quad \beta_{4x5} = 0.80, \quad \beta_{5x8} = 1.12, \quad \beta_{6x10} = 0.22, \quad \beta_{7x11} = 0.20 \text{(Table 6)}.$$ 

In this combination, the model can be represented by an equation of the form:

$$z' = 4.21 + 1.19 \cdot x_2 + 1.82 \cdot x_4 + 0.80 \cdot x_5 + 1.13 \cdot x_8 - 0.22 \cdot x_{10} + 0.20 \cdot x_{11}.$$
In the same way, in combination 3 in the model, the coefficients are used: $\beta_{2x2} = 2.69$, $\beta_{3x4} = 1.94$, $\beta_{4x5} = 0.34$, $\beta_{5x8} = 1.65$, $\beta_{6x10} = 1.19$, $\beta_{7x11} = 0.89$ (Table 4), and the model itself has the following form:

$$z' = 2.4 + 2.6 \cdot x_2 + 1.9 \cdot x_4 + 0.34 \cdot x_5 + 1.65 \cdot x_8 - 1.19 \cdot x_{10} + 0.89 \cdot x_{11}.$$ 

Thus, an analysis of the data in Table 6 (determination coefficient, Fisher’s coefficient, and Student’s criterion) shows that according to the 1st option, the most high-quality model can be constructed. It is also important to evaluate the significance of multiple regression.

4. Conclusion

Based on a meaningful analysis, a selection was made of factors affecting the resulting indicator of the duration of the technological process of building the aerial parts of transformable low-rise residential buildings, the factors were checked for inter-correlation with the establishment of functional relationships between them, and the significance of factors was estimated using the multivariate analysis technique. The quality of the constructed model was verified using three formal criteria: the coefficient of determination, the Fisher’s coefficient, and the Student criterion, respectively 0.955; 21.356; 0.977 for the selected option.

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