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FEATURES OF MECHANIZATION OF WORK DURING THE CONSTRUCTION OF BUILDINGS USING LOW-RISE CONSTRUCTION TECHNOLOGIES

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ABSTRACT

Currently, in Uzbekistan, the low-rise housing construction sector is in a stage of dynamic development and, as a rule, is aimed at developing the territories of suburbs and agricultural areas. First of all, the trend of growth in the volume of low-rise residential construction is due to the fact that the construction of low-rise buildings is much less expensive in comparison with the construction of high-rise residential buildings. In addition, the operating costs of low-rise residential buildings are significantly lower than high-rise ones, since there is no need to install expensive engineering equipment (elevator equipment, high-power pumping equipment, fire protection systems, etc.). State programs in the field of providing the country's citizens with affordable and comfortable housing provide for a comprehensive reduction in its sales value, which is primarily achieved by reducing the cost of construction, including by reducing the consumption of fuel and energy resources (FER) during the construction of buildings.

Keywords: energy, residence, exploitation, sketch, project, construction, design, architecture, premises, technology, configuration.

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1. INTRODUCTION

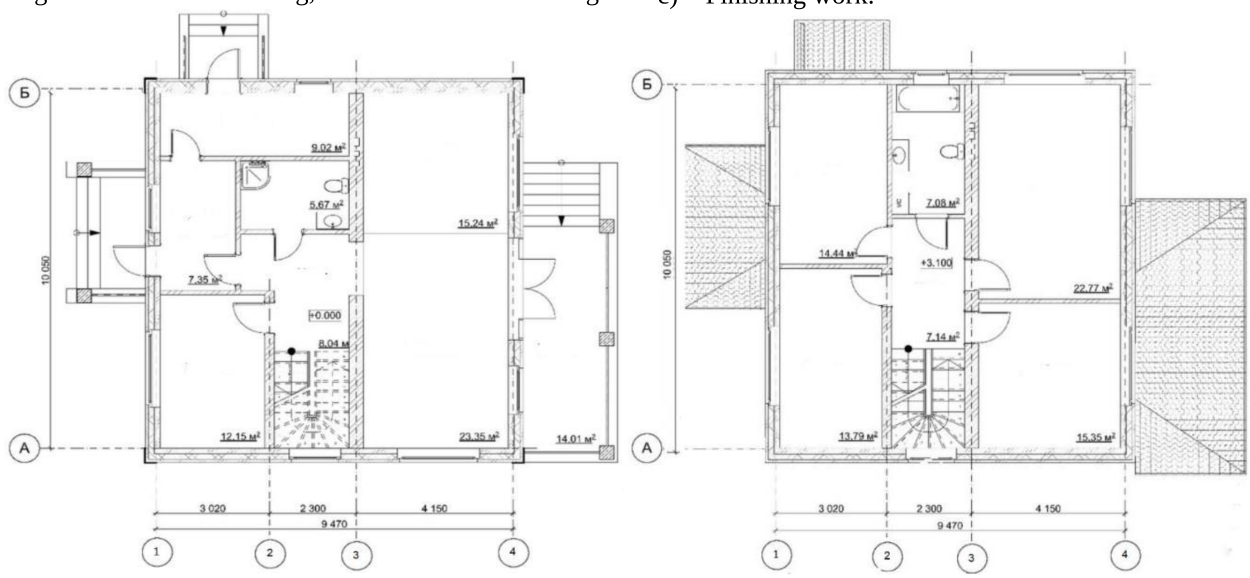
To conduct the study, the technologies that are currently most widespread in the practice of low-rise construction were selected:

- construction from brick: option No. 1;
- construction from lightweight concrete blocks (expanded clay concrete blocks): option No. 2;
- construction from permanent formwork in the form of polystyrene foam blocks with filling of the space between the formworks with a lightweight concrete mixture: option No. 3;
- construction from SIP panels: option No. 4 [1].

The project chosen for construction is a two-story rectangular residential building, which can be built using any of the low-rise housing construction technologies under consideration. Figure-1 shows a variant of the planning solution for a residential building using brick construction technology [2].

Each of the low-rise construction technologies under consideration can be broadly divided into the following stages of work on the construction of a building on a construction site:

a) Excavation and foundation work.
b) Work on the construction of the above-ground part of the building:
   - work on the construction of building walls;
   - work on the installation of floors;
   - roofing.
c) Finishing work.



a b

Figure-1. Planning solution for a low-rise brick residential building: 1st floor plan (a), 2nd floor plan (b).

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The consumption of energy resources during work with varying degrees of mechanization depends on the type and technological parameters, as well as the number of machines and mechanisms necessary for their implementation. As a result, the consumption of fuel and energy resources is determined based on the technical capacity and operating time of the labor mechanization equipment used [3, 4, 5].

When building from piece materials, such as brick and expanded clay concrete blocks, the main technological process for erecting the walls of a building is manual masonry using cement mortar [6, 7]. At the same time, the masonry work itself does not involve the use of mechanized tools; however, technological mixing equipment is used to prepare the mortar at the construction site. In low-rise housing construction with small volumes of construction, electric concrete mixers or mixing plants are used as such equipment, the power and drum capacity of which are selected in accordance with the volume of work performed. The supply of bricks or blocks, as well as mortar, to the scaffolding of the second floor of the building, is carried out using a lifting crane [8, 9, 10, 11, 12].

The construction of building walls from permanent formwork is a technological process of manually installing polystyrene foam blocks with reinforcement secured [13,14,15,]. To connect the reinforcement, construction equipment is used: installations for manual welding, a pumping station with a press. Concreting of the resulting structure is carried out mainly using concrete pumps, and deep vibrators powered by the network are used to compact the concrete mixture [16,17].

2. MATERIALS AND METHODS

Installation of walls, made of SIP panels, is a mechanized process, which is carried out using lifting equipment. The light weight of the panels allows the use of a small-sized truck crane or manipulator crane with a lifting capacity of no more than 5 tons [18, 19, 20].

Energy consumption for electrical mechanization equipment is determined by their power, indicated in the relevant technical data sheets, and is measured in kW/hour. For construction vehicles operating on liquid fuel, fuel and energy resources consumption is characterized by consumption in liters per hour (l/hour). For the convenience of calculating and analyzing costs for various energy consumers, all types of fuel and energy must be brought into a comparable form that will objectively take into account their characteristics. In this regard, a universal dimension expressed in the amount of equivalent fuel (ce) [1] with a calorific value of 29300 kJ/kg should be used as such a unit. The conversion of electricity and liquid fuel into standard fuel is carried out in accordance with GOST R 51750-2001 in accordance [2], which states that the conversion of electrical, thermal energy and fuel into standard fuel is carried out according to their physical (energy) characteristics based on the following ratios:

- 1 kW•h = 3.6 MJ = 0.12 kg of fuel equivalent;
- 1 kg of diesel fuel is equal to 1.45 kg of fuel equivalent;
- 1 kg of gasoline is equal to 1.52 kg of fuel equivalent.

Converting various types of fuel and energy resources into equivalent fuel allows you to calculate both costs of the same name, i.e. costs of one or more types of energy resources used for the production of certain types of construction and installation work or technological processes on a construction site (for example, installation of floor slabs, preparation of masonry mortar, etc.), and group costs - the sum of the expenses of all types of costs of the same name [21,22,23], grouped by functional purpose and spent on the construction of the building in accordance with the selected construction technology.

The duration of operation of technical equipment was calculated based on the specified volumes of work on a low-rise building for each construction technology under consideration according to the collections of EniR, GESN, TER, etc. [24].

3. RESULTS AND DISCUSSIONS

The consumption of fuel and energy resources by various types of machines and mechanisms during the construction of walls of the selected construction project is presented in Table-1.

Table-1. Consumption of fuel and energy resources by machines and mechanisms during the construction of walls of a low-rise residential building.

Job title	Machines and mechanisms	Consumption TER	Time for mechanization work, hour	Energy consumption, kg. u.t.
Brick walls				
Preparation of masonry mortar	Concrete mixer Denzel B-160	0.7 kW/hour	5,2	0,44
Brick and mortar supply	Truck crane KS-3577	5.5 l/hour (D)	7,2	57,42
Total energy consumption:				57,86
Laying walls from expanded clay concrete blocks				

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Preparation of masonry mortar	Concrete mixer Denzel B-160	0.7 kW/hour	4,3	0,36
Supply of blocks and mortar	Truck crane KS-3577	5.5 l/hour (D)	3,5	27,91
Total energy consumption:				28,27
Construction of walls in permanent formwork				
Installation of reinforcement in straight walls	Pumping station with reinforcement press PA-80	4 kW/hour	12,0	5,76
	Welding inverter MMA-220	7 kW/hour	1,0	0,84
Concreting wall structures	Truck concrete pump ABN 15	7 l/hour (Д)	12,0	121,80
Compaction of concrete mixture	Deep vibrator IV-75	1.4 kW/hour	3,0	0,51
Total energy consumption:				128,91
Construction of walls and ceilings from SIP panels				
Supply of SIP panels	Crane arm Fassi F65B.0.24	5 l/hour (D)	26,4	191,4
Total energy consumption:				191,4

Floors in brick or concrete low-rise residential buildings are either monolithic or prefabricated from prefabricated reinforced concrete slabs.

The installation of a monolithic ceiling is carried out in removable formwork, the space of which is filled with concrete mixture. To obtain a high-strength monolithic structure, it is recommended to pour concrete at a time, so the concrete mixture is delivered to the construction site by concrete trucks, and supplied to the formwork using a concrete pump. Currently, small-sized concrete pumps with a full-rotating distribution boom and a delivery range of up to 15 meters are widely used in low-rise construction.

Hollow-core reinforced concrete slabs are used as prefabricated floors in low-rise housing construction. The light weight of such products and the low height of their delivery make it possible to use construction equipment with low lifting capacity - crawler or truck-mounted cranes up to 15 tons. Depending on the type of engine installed in the specified construction machines, energy consumption is determined in l/h or kW/h. The consumption of fuel and energy resources depends on the technical parameters of the machine engine, as well as the characteristics of the technological operations performed. For two options for constructing floors, Table-2 presents the duration of mechanized work calculated in accordance with established standards and the construction machines and mechanisms selected for their production with the hourly consumption of fuel and energy resources.

Table-2. Comparison of fuel and energy resources consumption during mechanized work on the construction of monolithic and prefabricated floors of a low-rise residential building.

Type of overlap	Job title	Machines and mechanisms	FER consumption	Time for mechanization of work, hour	Energy consumption, kg. u.t.
Monolithic	Laying concrete mixture	Truck-mounted concrete pump ABN 15	7 l/hour (D)	4,0	40,6
	Compaction of concrete mixture	Deep vibrator IV-75	1.4 kW/hour	1,0	0,17
Total energy consumption:					40,77
Prefabricated	Installation of floor slabs	Truck crane KS-3577	5.5 l/hour (D)	7,4	59,01
Total energy consumption:					59,01

The presented values characterize various quantitative indicators of energy resource consumption during the construction of monolithic and prefabricated floors. The construction of a monolithic ceiling is characterized by lower energy consumption in comparison with a prefabricated one, however, one should take into account the long construction time associated with additional work on the installation of formwork and a technological break during concrete hardening.

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Floors in buildings using SIP panel construction technology, as well as walls, are mounted using small-sized cranes. Installation of floors from prefabricated multilayer panels is carried out in a single technological process along with the installation of walls and roofing.

In low-rise residential buildings with walls made of brick, expanded clay concrete blocks or permanent formwork, foundations are mainly used on a natural foundation: slab monolithic and strip (monolithic or prefabricated).

The design of a slab monolithic foundation involves the construction of a foundation slab with a uniform thickness along the entire perimeter, and a strip-monolithic foundation is a horizontal strip running along the entire perimeter of the building and under the internal walls. To carry out the process in a short time and obtain a single monolithic structure, it is recommended that the concrete mixture be prepared and delivered to the construction site using concrete mixer trucks. The concrete mixture is placed into the fixed removable formwork of a strip and slab foundation with pre-reinforced concrete using a concrete pump. To compact the concrete mixture, special construction equipment is used - deep or surface vibrators. A truck-mounted crane is used to construct prefabricated foundation blocks. In the case of erecting a strip prefabricated or strip monolithic foundation under a lightweight construction of walls made of expanded clay concrete blocks, it is possible to lay it shallowly depending on the depth of soil freezing in comparison with the greater depth of laying the foundation under brick or monolithic concrete walls, which affects the construction time and consumption of fuel and energy resources.

When constructing the foundation of a building from SIP panels, it is necessary to take into account the relatively light weight of the building structure itself. In this regard, the most appropriate option is to construct a pile foundation using screw concrete or metal piles. In low-rise construction, energy-efficient small-sized pile-driving installations are usually used to immerse them in the ground. After screwing, the metal piles are cut to the required level and the heads are welded to them using a welding unit.

Differences in the technologies used for low-rise construction affect the nature of the use of various types of construction machines, equipment and power tools when constructing the foundation of a building. These features create differences in the duration of mechanization of work and the corresponding energy consumption (Table-3).

When comparing the construction of monolithic slab and strip foundations, the data shown shows that the operating time of machines and mechanisms in the case of construction in a monolithic strip under walls made of brick or monolithic concrete in permanent formwork is longer compared to concreting a monolithic foundation slab or foundation strip under walls made of expanded clay concrete blocks. It should be taken into account that after laying monolithic concrete in the foundation, it is necessary to take a technological break associated with its hardening, which increases the construction time of the building. Compared to walls made of brick and monolithic concrete, the lighter weight of a wall structure made of expanded clay concrete blocks allows the construction of a finely buried strip monolithic or prefabricated foundation, which reduces construction time and corresponding energy consumption. Along with the construction of a monolithic strip foundation and foundation slab, the construction of a prefabricated foundation is the most energy-intensive, because is a mechanized process for installing factory concrete blocks using a lifting crane, but is characterized by the lowest labor costs and construction time compared to other options.

Excavation work related to the planning and development of soil for a strip foundation or monolithic foundation slab is carried out using special construction equipment - bulldozers and excavators. The capacity and width of the excavator bucket depend on the type of foundation being built. Compaction of the base under the foundation is carried out using tampers powered by compressor units. To install a pile foundation for SIP panels, only planning of the foundation site is provided. The operating time and fuel and energy resources costs during mechanized excavation work for each type of foundation are presented in Table-4.

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Table-3. Comparison of fuel and energy resources consumption during mechanized work on the construction of the foundation of a residential building.

Type of foundation	**Job title**	**Machines and mechanisms**	**FER consumption**	**Time for mechanization of work, hour.**	**Energy consumption, kg. u.t.**
Monolithic slab	Walls made of brick, expanded clay concrete blocks, monolithic concrete				
	Welding reinforcement cage	Welding inverter MMA-220	7 kW/hour	0,6	0,50
	Laying concrete mixture	Truck-mounted concrete pump ABN 15	7 l/hour (D)	3,0	30,40
	Compaction of concrete mixture	Deep vibrator IV-75	1.4 kW/hour	0,8	0,13
Total energy consumption:					31,03
Belt recessed	Walls made of brick, monolithic concrete				
	Welding reinforcement cage	Welding inverter MMA-220	7 kW/hour	5,0	4,20
	Laying concrete mixture	Truck-mounted concrete pump ABN 15	7 l/hour (D)	3,6	36,54
	Compaction of concrete mixture	Deep vibrator IV-75	1.4 kW/hour	0,9	0,15
Total energy consumption:					40,89
Tape shallow	Walls made of expanded clay concrete blocks				
	Welding reinforcement cage	Welding inverter MMA-220	7 kW/hour	2,1	1,80
	Laying concrete mixture	Truck-mounted concrete pump ABN 15	7 l/hour (D)	1,5	15,23
	Compaction of concrete mixture	Deep vibrator IV-75	1.4 kW/hour	0,4	0,56
Total energy consumption:					17,59
Prefabricated recessed	Walls made of brick or monolithic concrete in permanent formwork				
	Installation of foundation blocks	Truck crane KS-3577	5.5 l/hour (D)	16,8	133,98
Total energy consumption:					133,98
Prefabricated shallow	Walls made of expanded clay concrete blocks				
	Installation of foundation blocks	Truck crane KS-3577	5.5 l/hour (D)	8,8	70,18
Total energy consumption:					70,18
Piling	Walls made of SIP panels				
	Driving metal piles into the ground	Pile driving installation "Swaymaster-5000"	2 l/hour (B)	6,0	17,40
	Welding caps to piles	Welding inverter MMA-220	7 kW/hour	4,1	3,44
Total energy consumption:					20,84

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Table-4. Comparison of fuel and energy resources consumption during excavation mechanized work for the construction of the foundation of a low-rise residential building.

Type of foundation	Job title	Machines and mechanisms	FER consumption	Time for mechanization of work, hour.	Energy consumption, kg. u.t.
Pile, strip, foundation slab	Site layout	Bulldozer Komatsu D31	6 l/hour (D)	1,6	13,92
Total energy consumption:					13,92
Tape fine	Development of soil for trenches	Excavator Hyundai R140LC-9S	10 l/hour (D)	1,0	14,5
recessed	Compacting the base under the foundation	Pneumatic rammer with compressor K24M	4 kW/hour	3,2	1,54
Total energy consumption:					16,04
Belt recessed	Development of soil for trenches	Hitachi ZX180 excavator	12 l/hour (D)	1,9	33,06
	Compacting the base under the foundation	Pneumatic rammer with compressor K24M	4 kW/hour	3,3	1,58
Total energy consumption:					34,64
Foundation slab	Pit development	Excavator JCB JS 130W	10 l/hour (D)	1,4	20,30
	Base seal under the foundation	Pneumatic rammer with compressor K24M	4 kW/hour	6,1	4,37
Total energy consumption:					24,67

For cladding the facades of low-rise residential buildings, there are currently various building materials that are selected based on the designs of load-bearing walls. For a building constructed from brick and expanded clay concrete blocks, ceramic facing bricks are usually used, and in the case of walls constructed with permanent formwork, external decorative finishing “wet facade” is used. Due to the lightweight construction of the building made from SIP panels, the facade finishing can be made of decorative plaster, siding or wood. Energy consumption for finishing options for the low-rise residential building under consideration is presented in Table-5.

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Table-5. Fuel and energy resources costs for cladding the facade of a low-rise residential building.

Type of foundation	Job title	Machines and mechanisms	FER consumption	Time for mechanization of work, hour.	Energy consumption, kg. u.t.
Ceramic facing brick	Brick walls				
	Preparation masonry mortar	Concrete mixer Denzel B-160	0.7 kW/hour	1,7	0,14
	Brick and mortar supply	Truck crane KS-3577	5.5 l/hour (D)	2,4	9,14
	Total energy consumption:				19,28
	Walls made of expanded clay concrete blocks				
	Preparation masonry mortar	Concrete mixer Denzel B-160	0.7 kW/hour	2,0	0,17
	Brick and mortar supply	Truck crane KS-3577	5.5 l/hour (D)	3,2	25,52
Total energy consumption:					25,69
"Wet facade"	Walls made of monolithic concrete in permanent formwork				
	Soil preparation	Mortar mixer PH-80	1.5 kW/hour	2,4	0,43
	Application of primer	Mortar pump CM 40	5,5 kW/hour	5,6	3,70
	Textured finish	Sandblasting machine with compressor K24M	4 kW/hour	2,2	1,06
Total energy consumption:					5,19
Siding	Walls made of SIP panels				
	Siding fastening	Electric screwdriver DeWALT DW 274 K	0.5 kW/hour	32,8	1,97
Total energy consumption:					1,97

Internal pre-finishing of building premises according to the variants of construction made of brick, expanded clay concrete blocks and monolithic concrete in permanent formwork is carried out using plaster solutions applied mechanically using mortar pumps. Finishing mortars are prepared directly on the construction site in mortar mixing plants (Table-6). In the case of constructing a building from SIP panels, pre-finishing of the premises is carried out using sheets of plasterboard, which are fastened using hand tools - screwdrivers.

Table-6. FER and energy resources costs for mechanized work on internal pre-finishing of building premises.

Job title	Machines and mechanisms	FER consumption	Work mechanization time, hour.	Energy consumption, kg. u.t.
Preparation of plaster mortar	Mortar mixer PH-80	1.5 kW/hour	4,7	0,85
Preparation of mortar for concrete floor preparation	Concrete mixer Denzel B-160	0.7 kW/hour	5,0	0,42
Applying plaster mortar to walls and ceilings	Mortar pump CM 40	5.5 kW/hour	48,8	32,21
Applying mortar for concrete floor screed			2,4	1,58
Total energy consumption:				35,06

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According to the project, for the selected low-rise residential building, it is planned to install a wooden truss system of a gable roof covered with roofing material - metal tiles. Work is carried out using hand-held mechanized tools, powered either by electricity (Table-7) or by batteries (screwdriver). To install roofs on buildings made from SIP panels, ready-made sandwich panels with a steel coating are usually used. Installation of such panels is carried out using lifting equipment, and fastening to each other by welding.

Table-7. Fuel and energy resources costs when installing the roof of a low-rise residential building.

Job title	Machines and mechanisms	FER consumption	Work mechanization time, hour.	Energy consumption, kg. u.t.
Walls made of brick, expanded clay concrete blocks or monolithic concrete in permanent formwork				
Sheathing device	Circular saw DeWALT DWE 576 K	1.5 kW/hour	2,5	0,45
Installation of counter-battens for sheathing under metal tiles			0,8	0,14
Metal roof installation	Angle grinder BOSCH GWS 660	0.7 kW/hour	1,0	0,08
Total energy consumption:				0,67
Walls made of SIP panels				
Installation of multi-layer roofing panels with profile sheeting	Crane-manipulator Fassi F65B.0.24	5 l/hour (Д)	0,80	5,80
Fastening panels by welding	Welding inverter MMA-220	7 kW/h	7,20	6,04
Total energy consumption:				11,84

As a result, various design and technological solutions are characterized by a corresponding energy consumption structure. Based on the analysis, Table 8 presents the calculated energy costs for the considered options for the construction of a low-rise residential building.

To compare the energy consumption of different construction options, it is advisable to introduce a comparative energy consumption index (I_e), which is defined as the ratio of the most energy-consuming quantitative indicator E_{max} to the indicator with comparatively lower energy consumption:

$$I_e = \frac{E_{max}}{E_i} \quad (1)$$

i = 1…n, where n - is the energy consumption for the i-th variant of the design and technological solution or construction technology.

So, when constructing a building using technology No. 1, when comparing options for foundation construction:

$E_{fund.max}$ = 182.54 kg.t. – excavation work and installation of a prefabricated strip foundation;
$E_{fund.1}$ = 89.45 kg.t. – excavation work and installation of a monolithic strip foundation;
$E_{fund.2}$ = 69.62 – kg.t. – excavation work and installation of a monolithic foundation slab.

Then, $I_{e(fund.1)} = \frac{182.54}{89.45} = 2,\ I_{e(fund.2)} = \frac{182.54}{69.62} = 2.6$

Calculations are made similarly for other options for low-rise housing construction technologies.

When comparing floor installation options for technology options No. 1-3:
$E_{cross.max}$ = 59.01 kg.t. – installation of prefabricated floors;
$E_{cross.1}$ = 40.77 kg.t. – installation of monolithic floors.

$$I_{e(cross.1)} = \frac{59.01}{40.77} = 1.4$$

As a result of the comparison, based on the indicators in Table-8, among the considered options for constructing foundations and floors, the least energy-intensive is the construction of a monolithic foundation slab ($I_{e(fund.)}$=2.6) and monolithic floors ($I_{e(overlap.)}$=1.4).

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Table-8. Energy consumption during mechanized work for variants of design and technological solutions (in kg standard weight).

<table>
<tr><th>Technology</th><th>Excavation</th><th>Foundation structure</th><th>Walling</th><th>Floor arrangement</th><th>Exterior finishing</th><th>Roofing</th><th>Finishing facilities</th></tr>
<tr><td rowspan="3">Option No.1</td><td>38,59</td><td>Monolithic slab - 31,03</td><td rowspan="3">57,86</td><td rowspan="3">Monolithic - 40.77
National team - 59.01</td><td rowspan="3">19,28</td><td rowspan="3">0,67</td><td rowspan="3">35,06</td></tr>
<tr><td rowspan="2">48,56</td><td>Belt recessed monolithic - 40,89</td></tr>
<tr><td>Belt recessed prefabricated - 133,98</td></tr>
<tr><td rowspan="3">Option No.2</td><td>38,59</td><td>Monolithic slab - 31,03</td><td rowspan="3">28,27</td><td rowspan="3">Monolithic - 40.77
National team - 59.01</td><td rowspan="3">25,69</td><td rowspan="3">0,67</td><td rowspan="3">35,06</td></tr>
<tr><td rowspan="2">29,96</td><td>Shallow tape monolithic - 17,59</td></tr>
<tr><td>Shallow prefabricated belt - 70,18</td></tr>
<tr><td rowspan="3">Option No.3</td><td>38,59</td><td>Monolithic slab - 31,03</td><td rowspan="3">128,91</td><td rowspan="3">Monolithic - 40.77
National team - 59.01</td><td rowspan="3">5,19</td><td rowspan="3">0,67</td><td rowspan="3">35,06</td></tr>
<tr><td rowspan="2">48,56</td><td>Belt recessed monolithic - 40,89</td></tr>
<tr><td>Belt recessed prefabricated - 133,98</td></tr>
<tr><td>Option No.4</td><td>13,92</td><td>Pile – 20,84</td><td colspan="2">191,40</td><td>1,97</td><td>11,84</td><td>-</td></tr>
</table>

4. CONCLUSIONS

Differences in the nature and dimension of fuel and energy resources consumption by various energy consumers at a construction site necessitate the conversion of all types of fuel and energy into a universal dimension - kilograms of standard fuel (kg equivalent) in accordance with GOST R 51750-2001.

The calculation and analysis of energy consumption in the production of mechanized work for the selected options for design and technological solutions revealed various quantitative indicators of energy consumption. To compare fuel and energy resources costs, a comparative energy consumption index (I_e) was introduced, which showed that among the considered options for constructing the foundation and floors of a low-rise residential building, the construction of a monolithic foundation slab ($I_{e(fund.)} = 2.6$) and monolithic floors ($I_{e(cross)} = 1.4$) is the least energy-consuming.

A study of energy consumption by temporary infrastructure facilities at a construction site for construction options from 5 to 30 low-rise residential buildings in relation to the low-rise housing construction technologies under consideration showed that differences in the structure of energy costs are largely determined by the timing and seasonality of construction. The obtained quantitative indicators of energy consumption by the temporary infrastructure of a construction site showed that the highest energy consumption occurs when constructing buildings made of brick (E_{max}), the lowest - from SIP panels ($I_{e(var.No.4)} = 11$).

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