Organizational and technological aspects of the design and construction of heat supply systems based on heat pumps in low-rise construction

Azarij Lapidus[1], *Vadim* Fedoseev[2], *Alexander* Sokolov[3], *Julia* Ostryakova[2] and *Vladimir* Voronov[2]

[1] Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia
[2] Department of Organization of Production and Municipal Economy, Ivanovo State Politechnical University, 21, Sheremetevsky avenue, Ivanovo, 153000, Russia
[3] Department of High-Voltage Electric Power Engineering, Electrical Engineering and Electrophysics, Ivanovo State Power Engineering University, 34, st. Rabfakovskaya, Ivanovo, 153003, Russia

Abstract. There are most of the energy`s costs are accounted for by heating and hot water supply in communal housing conditions. Every day there is a growing need for the development and development of alternative options for energy generation technology. In the field of alternative energy, the most popular solution is a heat supply system based on air heat pumps (HP). Construction and installation work is simplified for integrated heat pump systems, but the question of the organization of design for these devices remains not fully resolved. The purpose of the work is to study the features and patterns of design and construction works with heat pump systems built into the premises in the field of low-rise construction and to develop measures to reduce the time and cost of such works. Heat engineering calculations for integrated heat pump systems that take into account climatic features, architectural and construction elements and parameters of engineering networks of the construction object, increase the complexity, cost and duration of design work. The research methods used are the analysis of the entire design process and in particular the section "heating and ventilation", further modeling through network planning of the design process and comparison of the obtained data. The results of the study are calendar schedules of the design process of integrated heat pump systems on the example of a cottage structure with an area of 150 m^2. For further analysis, the parameters of the time reserves of the working processes of the obtained network graphs are calculated. The section of heating, ventilation and heat supply (S) for integrated heat pump systems of heat supply is compared with the classical one, where the heat generator is an electric boiler. As a result of the study, a scheme for organizing design work is proposed, which allows you to plan the design of the section S without affecting the overall terms of execution of project documentation and the growth of its cost.

1 Introduction

Heat supply systems based on HP in low-rise construction are well known to specialists; nevertheless, on the territory of the Russian Federation, this technological solution raises many questions regarding their effective use [1, 2].

The simplicity of installation work and the efficiency of heat generation are provided by built-in heat pump systems (HTP) based on HT. The efficient operation of the built-in heat pump system is determined by the heat engineering calculation with the linking of all parameters of the construction object at the design stage, this also implies an increase in the design time. It is necessary to improve the process of organizing design work of built-in heat pump systems so that the labor intensity of heat engineering calculations does not affect the increase in the overall design time of the construction object.

Such scientists as A.A. Lapidus, T.K. Kuzmina, D.V. Topchiy, T.Yu. Poznakhirko, A.Yu. heat pump systems [3-7].

2 Methods

The sequence, timing of such work and their relationship is carried out in accordance with network planning. For the design stage of the life cycle of a construction object, the characteristic parameters are the start and end dates of each work, their duration and the resources expended. In the process of network planning, such indicators are determined as several options for starting and ending work, while the methodology for calculating the network model implies the possibility of calculating only early and late dates.

The technology for creating network planning of design work is based on such parameters as the scope of work, constraints and risks. The stages of development of the schedule of design work are indicated in Table 1.

Table 1. Stages of development of the project work schedule.

№	Denomination	Description	Parameter
1.	Formation of the list of the scope of work	When determining the composition of operations, the method of sequential work decomposition is used.	Content of work
2.	Determination of project implementation potential	It is based on the duration of work and their sequence, which, in turn, depends on the technology of execution. To determine them, the methods of sequential decomposition and expert assessment are used.	
3.	Establishing resource availability	Human, material, financial, informational and other resources are involved in the design processes. Therefore, the work schedule must be correlated with the financing schedule. For this, the resources are differentiated according to the work distribution technology.	Limitations
4.	Defining external constraints	Common restrictions are - seasonality, supply of materials and equipment.	
5.	Risk response planning	For the main threats, given the risks of the project, it is necessary to include and develop a response plan, a forecast that can affect the schedule.	Risks

It is advisable to take a low-rise residential building with an area of 150 m^2 as an object of research. The calculation of the cost of design work was carried out on the basis of current regulatory documents, including the "Collection of prices for design work for construction" and using the specialized software, CMETA PIR.

To calculate the cost of developing a working project, the formula proposed in [8] is used:

$$C = (A + B) \cdot X, \quad (1)$$

where A and B are constant values for calculating the cost of developing working documentation in rubles. for a 2-storey residential building with outbuildings A = 4176, B = 0.22 [3]; X - coefficients to the developed stages of the project, the following were used for the calculation: 1.21 - working stage; 1.19 - residential and civil buildings, 29.2 - design work [8]. Then the cost of developing a working project, rubles, will be:

$$(4175 + 0,22) \cdot 1,21 \cdot 1,19 \cdot 29,2 = 175589. \quad (2)$$

As a rule, the typical value of the cost of developing the RV section (Table 2) with an electric boiler does not exceed only 7% of the total cost of work. However, this value is not correct to apply for built-in heat pump systems, since the calculations must take into account the specific climatic conditions of the region of the construction object. Similar actions must be taken when designing heat supply systems with an electric boiler. When developing a section of OM with a reference to climatic conditions, its cost always becomes higher and is calculated based on the percentage (30%) of the total project cost [8].

$$175589 \cdot 0,3 = 52676 \text{ руб.} \quad (3)$$

During the development of the RV section for built-in heat pump systems, the component of the design work organization is of great importance, since the mutual influence of the developed sections of the design documentation increases. In fig. 1 shows the sections of the design documentation, which are influenced by the decisions made when developing the RV section of the built-in heat pump system.

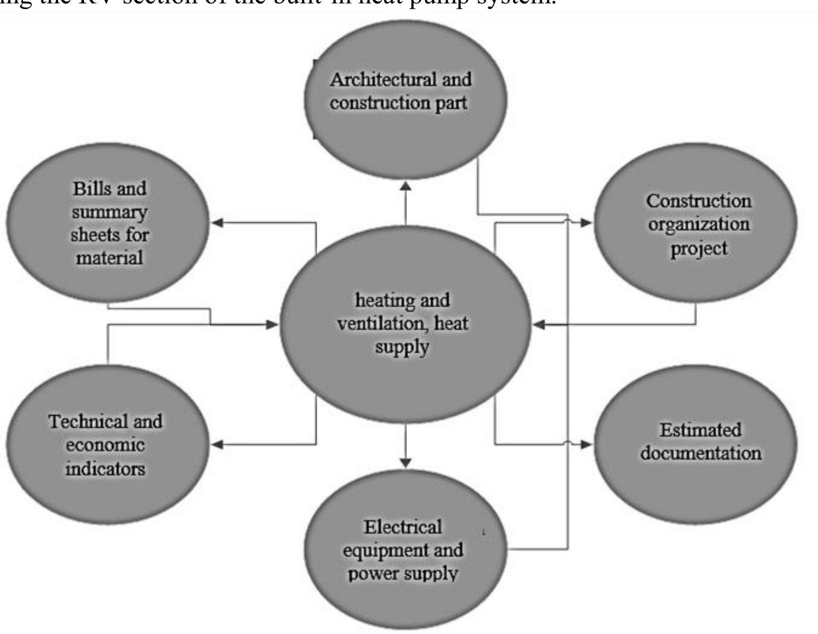

Fig. 1. Interrelation of sections of project documentation

For the rational organization of design work for an object with an integrated heat pump system, it is necessary to build a dynamic model of the production process. The best solution in this case is the development of a network schedule, since it reflects the technological sequence of work and their interconnection. To do this, it is necessary to assign each section of the project documentation its own number and determine the duration of the work - see table. 2.

Table 2. Initial data for building a network diagram.

Job number	The content of the work	Duration of work, days
0-1	Collection of initial data (CD)	7
1-2	Development of technical and economic indicators	2
2-3	Development of the architectural and construction section (AC)	21
2-4	Development of a general plan, vertical planning, land-scaping, small forms, on-site engineering networks	5
2-5	Assessment of the state and development of measures to improve the sanitary state of the environment	5
3-6	Development of the heating, ventilation and heat supply (RV) section	14
3-7	Development of a section of communication means and signaling (CM)	5
3-8	Development of the section for electrical equipment and power supply (EE)	7
4-9	Development of projects for external engineering net-works: water supply, sewerage, gas pipeline, hot water supply and drainage	5
9-10	Development of a bill and a summary bill of material re-quirements	5
9-11	Development of a construction organization project (COP)	5
9-12	Development of estimate documentation	9
12-13	Issuance of design documentation to the customer	1

The generated data (Table 2) are taken as input for the further construction of the network diagram of the design work process.

3 Results

Based on the generated initial data (Table 2), it is possible to build a network diagram model of the design work process - see fig. 2.

According to fig. 2, the development of sections RV, CM, EE is carried out only after the completion of the AC (Table 2). The AU section is the longest and is 21 days, the OV, CM and EE sections count respectively 14, 5 and 7 days. Taking into account the CD and COP sections, the critical (maximum) duration of the project will be 52 days. The network schedule for carrying out design work with an electric boiler as a source of heat supply will differ from that shown in Fig. 2 only by shorter terms of development of the OV section, which will be 7 days.

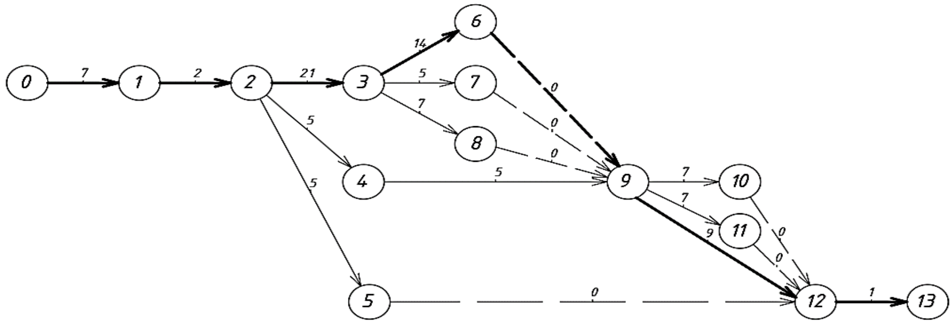

Fig. 2. Network schedule for the organization of design work (schedule No1)

Next, you should use the decomposition method, dividing the RV section into stages: the initial data of the ROV section (process 0-6.1), the calculation of the technological mode of operation of the HTN in the climatic conditions of the construction region (process 6.1-6.2), project development (process 6.2-6.3) and approval project (process 6.3-6.4). The first two stages fundamentally distinguish the production of design work for built-in heat pump systems from similar systems based on an electric boiler in view of the peculiarities of calculating the effective heat transfer of HTN [9,10].

When decomposing the RV section, the network schedule for organizing design work will take the form shown in Fig. 3.

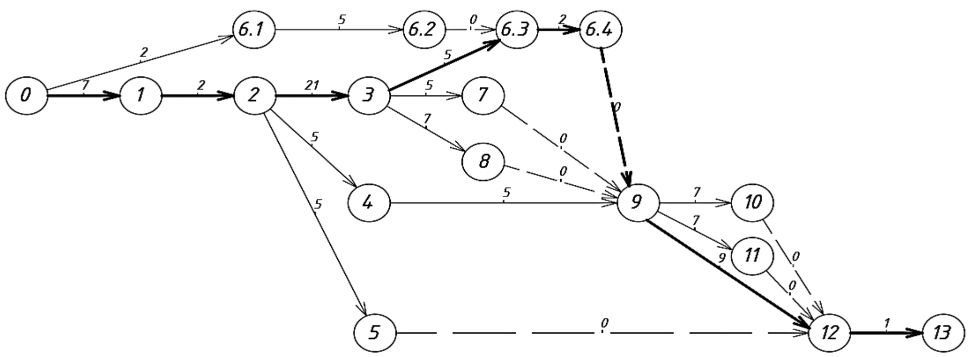

Fig. 3. Network schedule for the organization of design work in the decomposition of the RV section (schedule No2)

According to fig. 3, the first two stages of the RV section are not tied to the physical model of the construction object, and, consequently, to the AC part. When these components of the RB section are followed in parallel with the AC section, additional labor costs are not created in the form of adjustments. As a result of the implementation of such a redevelopment of the production process of the RV section, the completion date will coincide with the EE section, which means that the critical duration of design work will be reduced to 47 days.

4 Discussion

Using the capabilities of network planning, possible reserves of time for performing work on network schedules are determined. 2 and fig. 3. The results of calculating the reserve of time - see table. 3.4.

Table 3. Calculation of temporary reserves of working processes of the network schedule No1.

Job (i,j)	Early dates: start t_{ij}P.H.	Early dates: ending t_{ij}P.O.	Late dates: start t_{ij}П.H.	Late deadlines: ending t_{ij}П.O.	Time reserves: full R_{ij}П	Private reserve type I, $R_{ij}1$	Private reserve type II, R_{ij}C
0,1	0	7	0	7	0	0	0
1,2	7	9	7	9	0	0	0
2,3	9	30	9	30	0	0	0
2,4	9	14	34	39	25	25	0
2,5	9	14	39	44	30	30	0
3,6	30	44	30	44	0	0	0
3,7	30	35	39	44	9	9	9
3,8	30	37	37	44	7	7	7
4,9	14	19	39	44	25	0	25
9,10	44	49	48	53	4	4	0
9,11	44	49	48	53	4	4	0
9,12	44	53	44	53	0	0	0
12,13	53	54	53	54	0	0	0

Table 4. Calculation of temporary reserves of working processes of the network schedule No2.

Job (i,j)	Early dates: start t_{ij}P.H.	Early dates: ending t_{ij}P.O.	Late dates: start t_{ij}П.H.	Late deadlines: ending t_{ij}П.O.	Time reserves: full R_{ij}П	Private reserve type I, $R_{ij}1$	Private reserve type II, R_{ij}C
0,1	0	7	0	7	0	0	0
0,6.1	0	2	28	30	28	28	0
1,2	7	9	7	9	0	0	0
2,4	9	30	9	30	0	0	0
5	9	14	27	32	18	18	0
2,6	9	14	30	35	21	21	0
6.1,6.2	2	7	30	35	28	0	7
3,6.3	30	35	30	35	0	0	0
3,7	30	35	32	37	2	2	2
3,8	30	37	30	37	0	0	0
4,9	14	19	32	37	18	0	18
6.2,6.3	14	14	35	35	21	0	21
6.3,6.4	35	37	35	37	0	0	0
9,10	37	44	39	46	2	2	0

9,11	37	44	39	46	2	2	0
9,12	37	46	37	46	0	0	0
12,13	46	47	46	47	0	0	0

The decomposition of the RV section made it possible to construct a network schedule in which the duration of the critical path was reduced from 52 days to 47. Consequently, with a rational organization of design work, an increase in the development time for the RV section will not increase the total duration of the design work of the construction object, while for stages 6.1 and 6.2 a time reserve is provided in the form of a full reserve of time RijП of 28 days. A general analysis of the design work process for the RV section with the HTN system should be carried out in the form of a comparison with a similar section of the classical heat supply system. The results of such a comparison of the RV sections for HVH and classical heat supply systems are given in table. five.

Table 5. Comparative analysis of the development of RV sections for HVH and classical heat supply systems.

Heating system	Binding to the climatic features of the region	Duration of section development, days	Section development cost, rub.
Classic heating system with el. boiler	Yes	12	52 676
Built-in heat supply system based on VTH	Yes	15	52 676

Thus, by using the developed design workflow scheme, it is possible to avoid an increase in the cost of design work and the overall design time.

5 Conclusions

1. For construction projects with built-in heat pump systems, an increase in the labor intensity of the design process of the OV section is characteristic due to the high interconnection of the main technological sections of the design documentation and the need to take into account the climatic features of the construction region. This is necessary in order to ensure the required efficiency of heat supply during the operation of the HTN.

2. The proposed scheme for organizing design work for low-rise construction objects with high-voltage heating allows you to keep the cost of project production at a level corresponding to the use of classical heat supply systems, with insignificant differences in design time.

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