

# Research of Heat Characteristics of Frame-Tent Structures

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**Abstract.** Advantages and disadvantages of modern frame-tent constructions are considered in the article. Established there are some market offerings of heated buildings with a layer of thermal insulation, and without it. Now, there is no applied engineering calculation technique to define the heat losses from frame-tent constructions. Existing approaches don't allow to produce the correct results. It leads to exceeding or deficit of thermal energy supply in the building. In this work the real frame-tent building without a thermal insulation in Yekaterinburg equipped with an air heating system is considered. In the course of natural surveys, real transmission losses were defined from the heat and air balance. This value is exceeding the real capacity of the heating system in the building. It is also established, that the obtained coefficient of heat transfer of frame-tent structures is higher than normative values of thermal protection.

## 1. Introduction

Now, the frame-tent structures (prefabricated hangar tent structures) has widespread distribution on the construction market (Figure 1).



**Figure 1.** General view of a frame-tent structure.

Construction of these structures is a metal frame, with one or two layers of high-strength tent cover, made of a special synthetic fabric (with density about 750-1050 g/m<sup>2</sup>) which is made of polyvinyl chloride (PVC).

The wide distribution of frame-tent structures (as FTS) is due to a number of advantages:



1. Economical - low capital cost compared to traditional construction methods, due to the minimal time and resources for the FTS construction.
2. Mobility - construction design makes it easy to assemble and disassemble it without losing the technical and operational characteristics. This makes it possible to transfer the FTS without large financial losses.
3. Specifications - these structures are designed and constructed of lightweight materials that are characterized by fire safety, strength, resistance to mechanical damage.
4. Multifunctionality - frame-tent constructions can be used for various purposes. Perhaps it has its further expansion, addition, modification.
5. Easy installation - it does not require site preparation and complex equipment for installation.
6. Repairability – it is repaired easily and quickly: the fabric at any time can be replaced with a new one.
7. Large areas - the possibility of covering large areas with a minimum number of internal rigid elements.

On the other hand, there are also disadvantages:

1. PVC membrane does not have vandal-proof characteristics.
2. Tent structures are subject to fluctuations in the tent (vibration) under the influence of wind loads.
3. There are a large number of heat-conducting inclusions, they are difficult to cover in the joints of the tent.
4. High costs of heating (cooling) of infiltrating outside air, because the high infiltration and exfiltration
5. The complexity of the organization of heating and ventilation systems. It is associated with the consideration of real indicators of thermal protection of the FTS, and the consideration of air flows at the surfaces of external fences.

Despite the low thermal protection of the CTS, a number of manufacturers offer the installation of these structures without using of a special thermal insulation layer, including in the climatic conditions of the Urals and Siberia regions. Experience is showed a deviation of temperature mode (cooling) of the building, and the over-expanding of thermal energy in comparison with the project parameters.

It is obviously that a well-founded choice of the type and thickness of the layer of heat-insulating material will correctly determine the required heat capacity of the heating and ventilation systems. In this regard, the definition of the actual heat transfer coefficient of a frame-tent construction is an actual applied problem.

Problems of energy efficiency of a building with external enclosures with air interlayer are considered in the works of V. Bogoslovskiy [1]. The questions of determining the thermal characteristics of frame-tent structures are also covered in the publications of A. Fedorov and A. Tyutyunnikov [2].

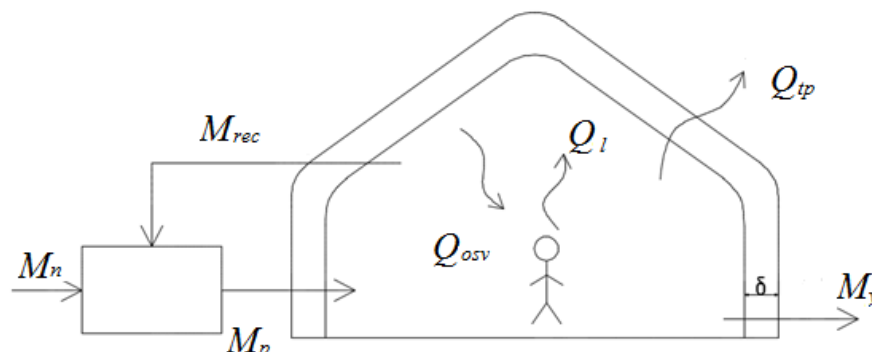
In the case of thermal engineering calculations, there is a formal approach of using the standard values for the heat transfer coefficients  $\alpha$ , W / (m<sup>2</sup> \* ° C) from the inner and outer surfaces of the walls. However, such an approach does not consider the movement of convective airflows inside space between tent layers, the effect of wind, the ratio of height and thickness, and also the angle of inclination of the air layer. All these factors have an effect on the formation of real heat transfer coefficients.

The purpose of this work is the experimental evaluation of the thermal characteristics of a heated frame-tent building.

Tasks:

1. Measuring the parameters of the heat balance of the building;
2. Calculation of transmission heat losses through the shell of the building;
3. Calculation actual heat transfer coefficient of a frame-tent construction.

To determine the heat transfer coefficient, temperature and air velocity measurements were made and (Figure 2).



**Figure 2.** Heat and air balance scheme.

$M_n$ ,  $M_p$ ,  $M_{rec}$ ,  $M_y$  – respectively, mass outflows of external, supply and circulating air, kg / s;  
 $Q_{osv}$ ,  $Q_l$  – heat input from lighting and people, Wt;  $Q_{tp}$  – transmission heat losses through external fences, Wt;  $\delta$  – thickness of the air layer between the tents, m.

The building has air heating, which is combined with a combined extract and input ventilation with partial recirculation. The supply air flow prevails over the flow rate: an excessive pressure is created inside the room: the air is removed through the leakage of the tengol cover to the foundation with the temperature of the working area ( $t_{wz} = +18^\circ\text{C}$ ). Measurements of air parameters in a skeleton-tent building for sports purposes were made. Measurements were made at different elevations with a time interval of 30 minutes (5 measurements). The average values are given in table 1.

**Table 1.** Measurements of heat and air balance parameters.

Nº	Measurement point	Speed, m / s	Dimensions, mm	Temperature, $^\circ\text{C}$
1	Recirculation grating	4,4-4,58	1400x800	20
2	Outlet connection of the supply air installation	-	$\varnothing 1250$	43,6
3	Air Intake grating	3,45 - 3,6	1950x950	0,5
4	Work zone			17,8-21
5	Space between tents			10,4

\* Measuring instruments: attested multi-function instrument testo-435-3; mercury laboratory thermometers of the type TL-1.

From the heat balance, the value of the thermal losses of the building was determined in the transition conditions, which is 352 kW ( $t_{ext} = 0.5^\circ\text{C}$ ). When calculating the value of heat loss for the design conditions ( $t_{ext} = -32^\circ\text{C}$ ), the thermal capacity of the equipment should be approximately 939 kW. At this facility, a heat generator is installed to compensate for the estimated heat loss of 363 kW ( $t_{ext} = -32^\circ\text{C}$ ). The obvious operational experience of the structure shows a shortage of heat during the cold period of the year to maintain the required air temperature in the work area.

As a result, the given coefficient of heat transfer of the outer guard of the CTS was  $2.99 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$ . According to other data [2], the value of the heat transfer coefficient is  $2.14 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$ , which is at variance with the data obtained. Both values exceed the heat transfer coefficient obtained with the use of thermal protection norms [3]:  $0.347 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$  for external walls. This shows that the use of a layer of additional thermal insulation in such structures is an actual measure.

To determine the required thickness of the insulation layer, the required resistance of the outer fence was calculated. According to the existing design, the construction without thermal insulation has a resistance to the heat transfer  $R_{\delta mu} = 0.334 \text{ (m}^2 \cdot ^\circ\text{C)/W}$ , and according to [3] the required normalized value is  $R_{\text{норм}} = 2.88 \text{ (m}^2 \cdot ^\circ\text{C) / W}$ . To meet the thermal protection requirements, thermal insulation was adopted in the form of mats manufactured using FORA technology (Russia), with a standard thickness of 100 mm [4]. In this case, the design resistance to heat transfer is  $R_{mu} = 3.56 \text{ (m}^2 \cdot ^\circ\text{C) / W}$ .

Estimation of the economic efficiency of the measures for the installation of additional insulation was carried out by calculating the payback period of additional thermal insulation according to the following data:

1. The tariff for natural gas is 4.16 rubles/m<sup>3</sup> gas (according to the Regional Energy Commission [5]).
2. Heat loss of the building during the billing period:
  - Without thermal insulation -  $Q_{\delta mu} = 939 \text{ kW}$
  - With thermal insulation -  $Q_{mu} = 110.5 \text{ kW}$
3. Duration of the heating period  $z = 221$  days;
4. The average outside air temperature for the heating period  $t_{om} = -5.4 \text{ }^\circ\text{C}$ ;
5. Design temperature of outdoor air in the cold period of the year  $t_{\text{нap}} = -32 \text{ }^\circ\text{C}$ ;
6. The calorific value of 1m<sup>3</sup> of natural gas is 9.2 kWh;
7. Capital costs for the thermal insulation device will be  $K = 3,267,152$  rubles (according to the data of the installation organizations).

After the heat insulation layer is installed, the heat costs for heat loss compensation will be reduced, and fuel costs will be reduced accordingly. The results of calculations for fuel costs are given in table. 2.

**Table 2.** Operating costs

№	Parameter	Without thermal insulation	With thermal insulation
1	Annual gas consumption, m <sup>3</sup> /year	281 112	33 097
2	Annual costs, rub.	1 169 425	137 683

The table shows that the annual savings amount to 1,031,787 rubles. At the same time, the payback period of thermal insulation will be 3 years and 3 months.

#### Conclusions:

- 1) the installation of a layer of thermal insulation for frame and tent structures is necessary to match fences with the norms of thermal protection of buildings and it is economically justified;
- 2) the using of standard heat transfer coefficients on the surfaces of external fences to determine the heat loss of frame-tent structures gives incorrect values of heat losses;
- 3) there is a lack of applied engineering methodology for calculating the reduced heat transfer coefficient of external fences for frame-tent structures and their energy indicators; the development of such a methodology based on the laws of heat and mass transfer is an actual and promising task.

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