Saimaa University of Applied Sciences
Technology, Lappeenranta
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Aleksandra Fanasiutkina

THE ORGANIZATION OF AIR EXCHANGE OF SKI TUNNEL

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ABSTRACT
Aleksandra Fanasiutkina
The organizasion of air exchange of sky tunnel
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Saimaa University of Applied Sciences, Lappeenranta
Technology, Civil and Construction Engineering
Tutors: Mr. Nikita Kharkov, Mr. Martti Muinonen

The purpose of this work was to develop one of the possible options of the air exchange on the section of the ski tunnel track. The object of studying was the ski tunnel designing now in Khanty-Mansiysk city (one of the two ever projected ski tunnels in Russia). Thermotechnical calculation of the walling was made according to the Russian regulations in the fourth chapter. Detailed calculation of the heat loss and the heat gain, calculation of the air parameters of ventilating system and air conditioning system for whole track and for the section of the ski tunnel track were made according to the Russian regulations using Microsoft Excel program in the forth and in the fifth chapters. Numerical simulation of the airflow on the section of the track based on the calculation data was made using Ansys Fluent program in the sixth chapter. As a result of this work parameters of the coolers, parameters of the air, a plan of ventilation allowing to provide required parameters of microclimate were obtained. The received results can be applied as reference material for designing ski tunnels.

Keywords: ski tunnel, air exchange, HVAC, sports facility

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Appendix 1 Mollier diagram for cold period
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1 INTRODUCTION

The ski tunnel is a sports facility, which is designed for year round competitions and trainings for ski sports. The ski tunnel is a long pipeline (several hundred meters) built of high-quality insulating materials. It allows practicing skiing by both professional and amateur athletes regardless of weather conditions and season of year. In the summer time and during bad weather in the winter the national teams of Norway, Russia or France, are forced to move to Finland or Austria, where ski tunnels are situated or the climate allows using of open ski trails. Ski tunnel excludes the need to provide expensive training camps in other countries.

The purpose of this work was to develop one of the possible options of the air exchange on the section of the ski tunnel track. For the realization of this goal the following tasks were assigned:

- Thermotechnical calculation of the walling.
- Calculation of the air parameters of ventilating system and air conditioning system.
- Numerical simulation of the airflow on the section of the track based on the calculation data.

As a basic object of the research was selected the overground ski tunnel in Khanty-Mansiysk city in Russia (the design is being produced currently). The ski tunnel is designed for 150 athletes, the tunnel length is 1 km, height is from 6 m to 8 m, and width is 12 m.

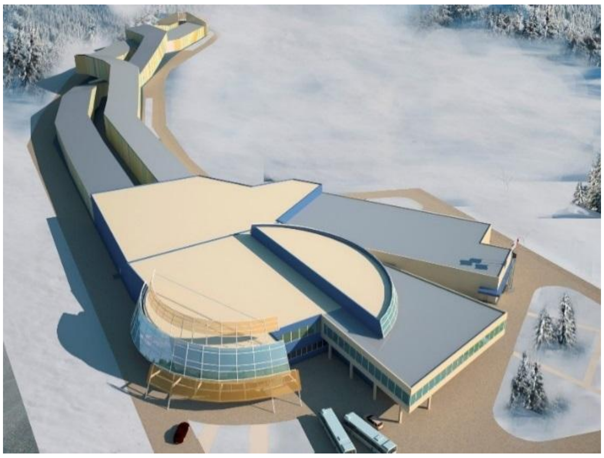


Figure 1 Three-dimensional model of the ski tunnel in Khanty-Mansiysk

This work was developed in collaboration with HVAC-engineer Nikita Kharkov, based on information of the contractor company which is engaged in the designing of this tunnel.

2 SKI TUNNELS IN THE WORLD

The world’s first ski tunnel was built in 1997 in Vuokatti, Finland. The purpose of creation was to create the ideal conditions for athletes on natural snow cover in the summer. The tunnel is located overground, has a rounded head start, length - 1210 m, width - 8 m, height - 4 m. Level difference is 51 m. The temperature in the tunnel is from -5 °C to -9 °C. After recoupment of expenses of the ski tunnel in Vuokatti, similar tunnels began to appear in other parts of Finland and in other countries.

The world's first underground tunnel "Kamppi", Leppavirta (Finland) was opened in the summer of 2004. "Kamppi" is located at a depth of 30 m, the basic cycle total length (four tracks) - 1.5 km. Throughout the year the powerful cooling system keep the temperature at -3 °C.

The world's largest and first ski tunnel in Central Europe was built in Oberhof (Germany) in 2009. Its length - 2.4 km, width - 7 m, height - 4 m. The ski tunnel is located above the ground and has a rectangular shape. The project is commercial, therefore it is intended not just for athletes, but also for tourists.

The first ski tunnel in North America "Peruvian Tunnel" was opened in December 2006 near Salt Lake City (Utah) in the ski resort Snowbird. It was built inside the mountain and the construction took almost a year of excavation and blasting to connect one side of the mountain with the other. The tunnel is not designed for skiing, the goal was to facilitate access to new slopes. The tunnel has a moving floor with a capacity of 1800 people per hour, which gives athletes from one hillside to another.

3 DESCRIPTION OF THE OBJECT

3.1 General part

The object: The ski training tunnel, Khanty-Mansiysk (Russia).
The purpose of the ski tunnel: training for ski sports.
The number of athletes at the same time (maximum): 150 people.

The customer of the tunnel is the government of the Tyumen region. The general contractor is CJSC “VNCC”. The design of the tunnel started in 2013 and the construction continues now.

The main characteristics of the facility: area – 8223.1 m^2, height - 6.6 to 8.2 m. The plan view of the ski tunnel is shown in Figure 2. The plan view and cross section views of the section in the axes 1/1-2/1 are presented in Figure 3, 4.

The architectural and planning concept of the ski tunnel, Khanty-Mansiysk, was taken on a custom design and developed based on customer's performance specification and Development plan of land plot. Designed building of the tunnel has a intricate shape in plan view. The tunnel is a single story building with a double-pitch roof and elevation in accordance with the requirements of ski tracks, with external drain system. The maximum building height at the ridge of the roof – 15.11 m, minimum – 7.61 m. The tunnel is a steel frame with walling, which is made of sandwich panels "Thermaland" [1].

Because of the functional purpose the building has an uneasy floor plan.
Design temperature is - 5°C.

As insulation the following materials are taken:

- for the exterior walls - wall sandwich panel "Thermaland", thickness 80 mm;
- for the cover and tunnel’s bottom broach over driveways and walkways - roof sandwich panel "Thermaland", thickness 100 mm;

Exterior doors are steel [2], interior doors - wood [3]. Window units in the tunnel are double glazing units in single PVC cover [4]. Reduced thermal resistance - 0.5 $m^2 \cdot {}^{o}C/W$, the shading coefficient $\tau = 0.8$, the relative solar transmission coefficient k = 0.74 p.12 app. L [5].

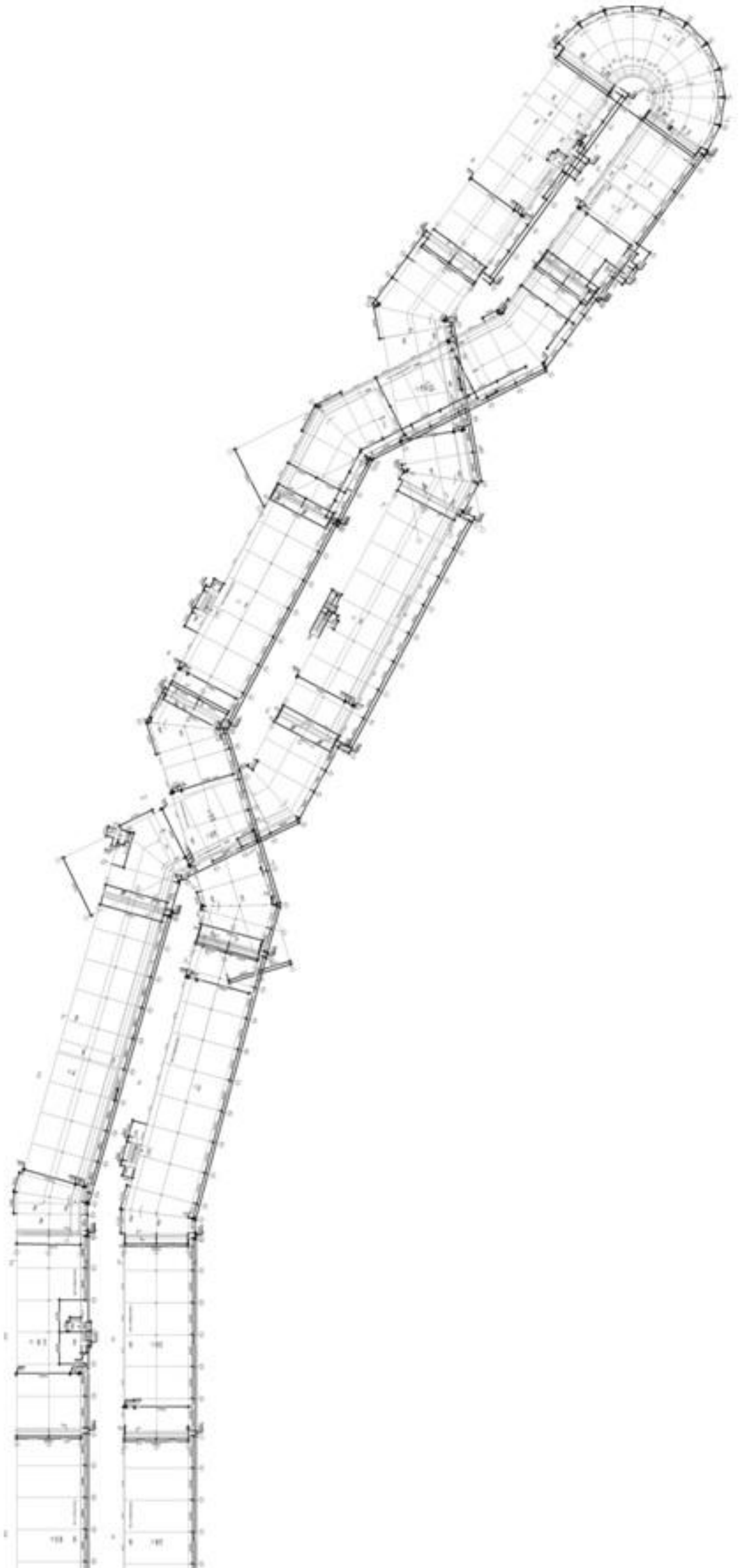


Figure 2 Plan view of the ski tunnel

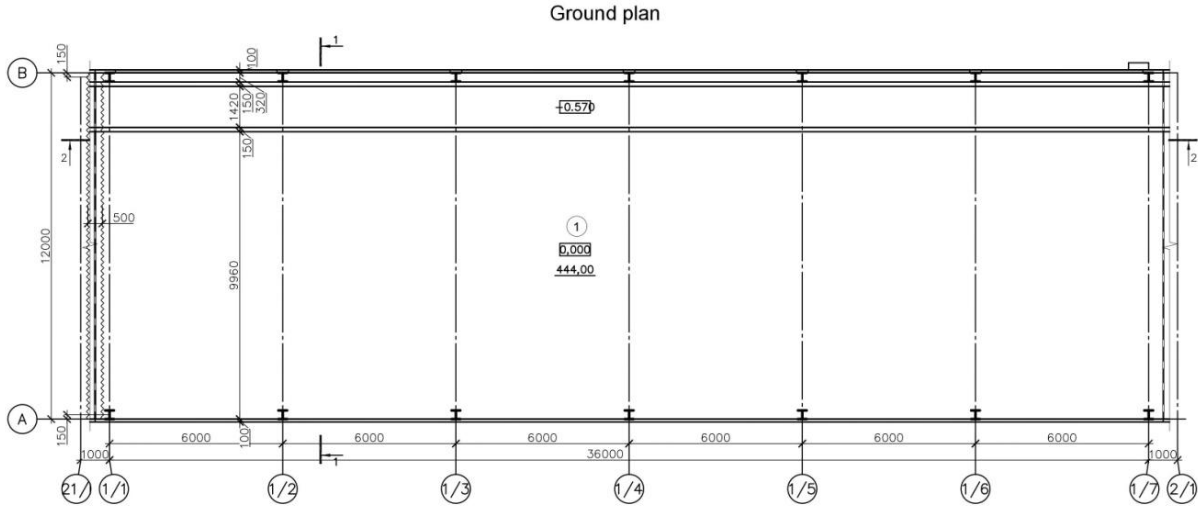


Figure 3 Plan view of the section in the axes 1/1-2/1

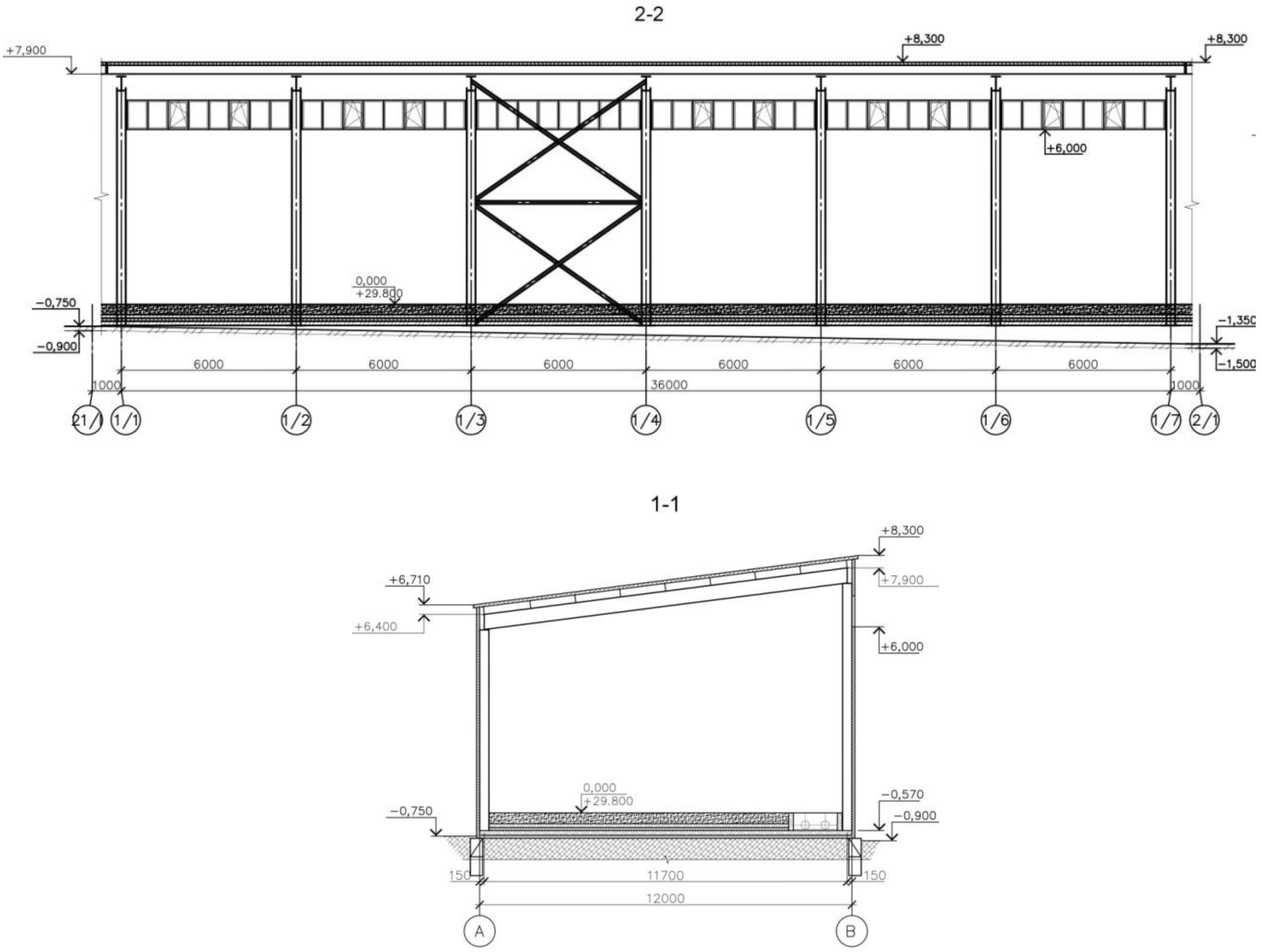


Figure 4 Cross section views of the section in the axes 1/1-2/1

3.2 Information about climatic and meteorological conditions of the construction area

Design parameters of outdoor air for the climatic region (Khanty-Mansiysk) are shown in Table 1 [6].

Table 1 design parameters of outdoor air

Design parameter		Warm period	Cold period
The conditioning	Temperature, °C	+22,7	-41
	Enthalpy, kJ/kg	+53,3	-44,3
	Relative humidity, %	70	82
Design barometric pressure , GPa		1005	

Geographic latitude 61.1° N.

3.3 Requirements for the premises

Parameters of the inner air are presented in Table 2.

Table 2 Parameters of indoor air

Parameters of air in working space (1.5 m above the surface of the snow)		
Temperature, °C	Relative humidity, %	Airspeed, m/s
-5	40–55	< 0,5

3.4 Air conditioning systems

Ventilation systems combined with air heating and local air coolers are provided in the project to ensure the required temperature and relative humidity of indoor air of ski tunnel. Air exchanges in the premises of the tunnel are determined by calculation with accounting the heat loss and the heat gain through outer shells and heat gain, moisture gain from the lighting and people (taking into account critical coefficients of thermal resistance of walling).In the cold period of the year ventilation plants are working for air heating of the indoor tunnel and in the warm period of the year ventilation plants are working without cooling incoming air. Indoors local air-to-air charge air coolers, which are located along the tunnel for better air distribution, are bringing the temperature to the rated amount -5°C.

4 CALCULATION OF VENTILATION AND AIR-CONDITIONING

4.1 Thermotechnical calculation

According to item 5.3 [7] normalized heat transfer resistance of the walling was determined by the formula:

$$R_{norm} = a \cdot D_d + b \,, \qquad (1)$$

where:

R_{norm} – normalized heat transfer resistance, m²·˚C/W;

a – the coefficient from table 4 [7]. For exterior walls a = 0.0003, for coating a = 0.0004, for windows a = 0.00005;

D_d – degree day of the region, ˚C [6]:

$$D_d = (t_{int} – t_{ht}) \cdot z_{ht} \,, \qquad (2)$$

where:

t_{int} – the temperature of the internal air, $t_{int} = -5˚C$;

t_{ht} – the average outdoor temperature during the heating period, $t_{ht} = -\ 8.8˚C$ [6];

z_{ht} – the duration of the heating period, $z_{ht} = 270$ days [6];

$$D_d = (-5 + 8.8) \cdot 270 = 1028 \text{ ˚C·days};$$

b – the coefficient from table 4 [7]. For exterior walls b = 1.2, for coating b = 1.6, for windows b = 0.2;

The normalized heat transfer resistance of exterior walls (1):

$$R_{wall.\ norm} = 0.0003 \cdot 1028 + 1.2 = 1.51 \text{ m²·˚C/W}.$$

The normalized heat transfer resistance of coating (1):

$$R_{roof.\ norm} = 0.0004 \cdot 1028 + 1.6 = 2.01 \text{ m²·˚C/W}.$$

The normalized heat transfer resistance of windows (1):

$$R_F = 0.00005 \cdot 1028 + 0.2 = 0.25 \text{ m²·˚C/W}.$$

The reduced heat transfer resistance of the walling was defined according to 2.6 [8] by the formula:

$$R_w = 1/\alpha_{in} + \delta / \lambda + 1/\alpha_{out}, \qquad (3)$$

where:

R_w – reduced heat transfer resistance of the walling, m²·˚C/W;

α_{in} – heat transfer coefficient of the inner surface of the walling was determined according to table 4 [8], $\alpha_{in} = 8.7$ W/ m²·°C;

δ – construction thickness, mm;

λ – coefficient of thermal conductivity of material, W/m·°C;

α_{out} – heat transfer coefficient of the outer surface of the walling was defined by the table 6 [8], α_{out} = 23 W/ m²·°C.

Exterior walls - sandwich panels "Thermaland" [1]: λ = 0.048 W/m·°C, thickness δ = 80 mm.

The reduced heat transfer resistance of exterior walls (3):

$$R_{wall} = 1/8.7 + 0.08/0.048 + 1/23 = 1.82 \text{ m}^2\cdot{}^\circ\text{C/W},$$

$$1.82 \text{ m}^2\cdot{}^\circ\text{C/W} > R_{wall.\ norm} = 1.51 \text{ m}^2\cdot{}^\circ\text{C/W}.$$

Building coating - roof sandwich panels "Thermaland" [1]: λ = 0.048 W/m·°C, thickness δ = 100 mm.

The reduced heat transfer resistance of coating (3):

$$R_{roof} = 1/8.7+0.1/0.048+1/23 = 2.24 \text{ m}^2\cdot{}^\circ\text{C/W},$$

$$2.24 \text{ m}^2\cdot{}^\circ\text{C/W} > R_{roof.\ norm} = 2.01 \text{ m}^2\cdot{}^\circ\text{C/W}.$$

According to 5.6 [7], reduced heat transfer resistance R_w, m²·˚C/W of translucent structures (windows) was accepted by certification tests. In the absence of the results of certification tests values are taken from the set of rules.

The windows in the heat point - triple-pane glass in aluminum frames. Reduced heat transfer resistance - 0.5 m²·˚C/W [4], the shading coefficient τ = 0.8, the relative solar transmission coefficient k = 0.74 item 12 app. L [5]. The coefficient of influence of the oncoming heat flow K=1.0. The results of the calculation are presented in Table 3.

Table 3 Properties of walling

Walling	Heat transfer resistance, m²·˚C/W	U-value, W/ m²·°C
Exterior walls	1.82	0.549
Coating (roof)	2.24	0.446
Windows	0.5	2

4.2 Calculation of moisture gain

Moisture gain from athletes was defined by the formula, g/h:

$$W = n \cdot m\ , \qquad (4)$$

where:

n – the amount of people;

m – the amount of moisture emitted by one adult (male), g/h, depends on the temperature of the internal air and the category of works (for heavy work, the indoor temperature - 5°C, m =110 g/h, according to [9]).

$$W = 150 \cdot 110 = 16500\ g/h\ .$$

4.3 Calculation of heat gain from athletes

Heat gain from athletes was determined by the formula, W:

$$Q_p = n \cdot q_p, \qquad (5)$$

where:

Q_p – the amount of heat;

n – the amount of people;

q_p – the amount of heat generation emitted by one adult (male), g/h, depends on the temperature of the internal air and the category of works (for heavy work, the indoor temperature - 5°C, q_p = 290 W according to table 9 [10]).

$$Q_p = 150 \cdot 290 = 43.5\ \text{kW}.$$

4.4 Calculation of heat gain from artificial lighting

Heat generations from artificial lighting were determined by the formula, W:

$$Q_{light} = E \cdot A \cdot q_{light} \cdot h_{light}\ , \qquad (6)$$

where:

q_{light} – average specific heat generation of the lamps, q_{light} = 0.094 W/lx·m^2 (for a floor area more than 200 m^2 and a height more than 4.2 m);

A – floor area, m^2;

E – level of illumination in the room space, E = 500 lx (according to [11]);

h_{light} – the coefficient considering the placement of the lamp h_{light} =1 (directly in the room);

$$Q_{light} = 500 \cdot 8037 \cdot 0.094 \cdot 1 = 377.739\ \text{kW}\ ;$$

$$Q_{light\ .design} = 377.739 \cdot 30\% = 113.32\ \text{kW}\ .$$

4.5 Calculation of heat loss through the outer shell in the cold period

Heat gain through the outer shell was determined by the formula, W:

$$Q_{shell} = S \cdot k \cdot (T - t), \tag{7}$$

where:

S – area of the walling, m^2;

k – U-value, $W/m^2 \cdot °C$, Table 3;

T– design outdoor temperature, °C;

t – design internal temperature, °C;

Area of the window:

$S_{wind} = 873 \cdot 0.54 = 471.4\ m^2$;

Area of the walls:

$S_{wall} = 8.2 \cdot 668 + 6.6 \cdot 705 - 471.42 = 9656.2\ m^2$;

Area of the roof:

$S_r = 12.1 \cdot 687 = 8312\ m^2$;

$$Q_{shell} = (9656.2 \cdot 0.549 + 8312 \cdot 0.446 + 471.4 \cdot 2) \cdot (-4 -(-5)) = -358.23\ kW.$$

4.6 Calculation of heat loss by infiltration in the cold period

The firing rate Q_i, W, for heating the infiltrated air was determined (by reference book to [12]) by the formula:

$$Q_i = 0{,}28 \sum G_i \cdot k_i \cdot c \cdot (t_p - t_i), \tag{8}$$

where:

G_i – the amount of the infiltrated air, kg/h, through the fencing of the room space:

$$\sum G_i = \frac{\sum A_1 \cdot \Delta p^{0,67}}{R_1}, \tag{9}$$

where:

A_1 – area of the windows, $A_1 = 471.4\ m^2$,

R_1 – resistance to the air-penetration of windows ($m^2 \times h(daPa)^{2/3}/kg$), by app.1 to reference book $R_1 = 0.29$;

Δp – calculated pressure difference between the outer and inner surfaces of the outer shells, daPa, by [13] app.10:

$$\Delta p = h_i(\gamma_{out} - \gamma_{in}) + 0{,}5v^2 \rho_{out}(C_w - C_l)K_1 - P_{in}, \tag{10}$$

where:

h_i – the estimated height from the top of the windows, doors, gates or openings in the exterior fencing of buildings to the level of the top of the outer wall, the base of the lamp or the mouth of the ventilating shaft, h=1,6м;

γ_{out}, γ_{in} – specific gravity, N/m^3, of outside air and air in the building with the temperature t °C was determined by the formula:

$$\gamma_{out} = 3463/(273\text{-}t), \qquad (11)$$

where:

t – air temperature, °C;

$$\gamma_{in} = 3463/(273-5) = 12.9 \text{ N/m}^3;$$

$$\gamma_{out} = 3463/(273-41) = 14.9 \text{ N/m}^3;$$

ρ_{out} – density of the outside air, kg /m^3;

$$\rho_{out} = \gamma_{out} / 9.81 \text{ kg/m}^3 , \qquad (12)$$

$$\rho_{out} = 14.9 / 9.81 = 1.52 \text{ kg/m}^3 ;$$

v^2 – wind speed, m/s, app.8 [13] v = 6.9 m/s;

C_w, C_l – aerodynamic coefficients for windward and leeward surfaces of shells of buildings, taken by App.4 [14], C_w, = 0.8, C_l = -0.6;

K_1 – the coefficient considering changes in velocity pressure depending on the building height and the type of district taken by the app.3 to the reference book, K_1 = 1;

$\Delta p = 1.5(14.9 - 12.9) + 0.5 \cdot 6.9^2 \cdot 1.52(0.8 + 0.6)1 - 0 = 72.5Pa = 7,25$ daPa;

P_{in} – relatively static air pressure in the structure, Pa, P_{in} = 0 Pa;

$$\sum G_i = \frac{447.7 \cdot 7.25^{0.67}}{0.29} = 5820.1 \text{kg/h} = 1.617 \text{ kg/s};$$

c – specific heat of air, c = 1 kJ /(kg×°C);

k_i – the coefficient considering the influence of oncoming heat flow in structures taken from app. 9 [15], k = 0.8;

t_p, t_i – the estimated air temperatures, °C, indoor and outdoor air in the cold period (options B);

$$Q_i = 0.28·1.617·0.8·1·(-41+5) = -13.037 \text{ kW}.$$

4.7 Calculation of heat gain through the outer shell in the warm period

Heat gain through the outer shell was determined by the formula (7):

$$Q_{shell} = (9656.2·0.549+8312·0.446+471.4·2)·(22.7-(-5)) = 275.64 \text{ kW}.$$

4.8 Calculation of heat gain by infiltration in the warm period

The firing rate Q_i, W, for cooling the infiltrated air was determined by the formula (8). Specific gravity, N/m^3, of outside air and air in the building was determined by formula (11):

$$\gamma_{out} = 3463/(273\text{-}5) = 12.9 \text{ N/m}^3;$$

$$\gamma_{in} = 3463/(273+22,7) = 11.7 \text{ N/m}^3;$$

According to formula (12), density of the outside air:

$$\rho_{out} = 11.7/9.81 = 1.19 \text{ kg/m}^3;$$

According to formula (10), calculated pressure difference between the outer and inner surfaces of the outer shells:

$$\Delta p = 1.5(11.7 - 12.9) + 0.5 \cdot 6.9^2 \cdot 1.19(0.8 + 0.6)1 - 0 = 37.9 Pa = \\ = 3.79 daPa;$$

According to formula (9) the amount of the infiltrated air, kg/h, through the fencing of the room space:

$$\sum G_i = \frac{447.7 \cdot 3.79^{0.67}}{0.29} = 3765.2 \text{kg/h} = 1.046 \text{ kg/s} \quad ,$$

$$Q_i = 0.28·1.046·0.8·1·(22.7+5) = 6.49 \text{ kW}.$$

4.9 Calculation of heat gain from solar radiation through the light apertures in the warm period

Heat flow, W, from solar radiation through the light apertures was calculated by the formula (according to [10]):

$$Q_{gl,i} = (q_{dir} + q_{dif})K_1K_2K_{comp}A_{gl}, \qquad (13)$$

where:

q_{dir}, q_{dif} – surface heat flow rate, W/ m^2, through the glassed light apertures in July in definite hour of the day, from direct solar radiation (q_{dir}) and from diffused solar radiation (q_{dif}), were taken from table 1 [10]. Surface heat flow rates are shown in Table 4;

$$q = q_{dir} + q_{dif}, \qquad (14)$$

K_{comp} – the coefficient of heat passing-through glassed area light, K_{comp} = 0.74 according to p.12 app. L [5], also by p. 3.8 [8] the coefficient of heat passing for sun-protection device is 0.4, K_{comp} = 0.74 * 0.4 = 0.296;

K_1 – the coefficient considering soiling of the glass, K_1 = 0.95;

K_2 – the coefficient considering shading of the glass, K_2 = 0.80;

A_{gl} – the area of the light apertures (the glasses), m^2, the area of one window A_{gl1} = 0.54 m^2 (0.9 m * 0.6 m), all windows are the same.

$$A_{gl} = A_{gl1} \cdot n, \qquad (15)$$

where n – the amount of the light apertures (Table 5).

Table 4 Surface heat flow rate

	q, W/ m^2						
Current hour	E	W	NE	SW	SE	N	NW
8-9	608	50	223	60	599	55	52
9-10	455	51	81	65	593	51	53
10-11	258	53	55	139	536	51	53
11-12	97	56	55	286	437	50	53
12-13	56	97	53	437	286	50	55
13-14	53	258	53	536	139	51	55
14-15	51	455	53	593	65	51	81
15-16	50	608	52	599	60	55	223
16-17	45	667	50	537	49	57	414
17-18	40	649	43	398	40	59	490

Table 5 Amount of light apertures

	E	W	NE	SW	SE	N	NW
n, unit	96	226	281	194	46	18	12

The calculation of the heat gain from solar radiation through the light apertures oriented to the East from 8 to 9 a.m.:

$$Q_{gl} = 608 \cdot 0.95 \cdot 0.80 \cdot 0.296 \cdot 0.54 \cdot 96 = 7090 \text{ W}.$$

The results of calculation of heat gain from solar radiation through all light apertures are presented in Table 6.

Table 6 The heat gain from solar radiation through light apertures

	Q, W							
Current hour	E	W	NE	SW	SE	N	NW	∑
8-9	7090	1373	7612	1414	3347	120	76	21033
9-10	5306	1400	2765	1532	3314	112	77	14506
10-11	3009	1455	1877	3276	2995	112	77	12801
11-12	1131	1537	1877	6740	2442	109	77	13915
12-13	653	2663	1809	10299	1598	109	80	17212
13-14	618	7083	1809	12632	777	112	80	23111
14-15	595	12492	1809	13975	363	112	118	29463
15-16	583	16692	1775	14117	335	120	325	33947
16-17	525	18312	1707	12655	274	125	604	34201
17-18	466	17818	1468	9380	224	129	714	30198

4.10 Calculation of heat gain from solar radiation through the massive walling in the warm period

Heat flow, W, from solar radiation through the massive walling was calculated by the formula (according to [10]):

$$Q_{\text{м},i} = \left[\frac{1}{R} \rho \frac{J_{\text{ср}}}{\alpha_{\text{нар}}} + \frac{\beta_{\text{к}} \cdot \alpha_{\text{вн}}}{\text{V}} (0{,}5\Theta_1 A_{\text{мс}} + \frac{\rho}{\alpha_{\text{нар}}} \Theta_2 A_j) \right] A_{\text{м}}, \qquad (16)$$

where:

R – heat transfer resistance;

β_κ – the coefficient equals 1 - in the absence of a ventilated air gap in the walling (cover);

$\alpha_{in}, \alpha_{out}$ – the heat transfer coefficients of the inner and the outer surface of the W/(m^2·°C), were determined by the formula (24) and table 4* [8], for walls and smooth ceilings α_{in} = 8.7 W/ m^2·°C, $\alpha_{out} = 23$ W/ m^2·°C;

V– value of outdoor temperature oscillation damping in the walling was determined by the formula

$$V = 2^D \cdot (0.83 + 3\frac{R}{D})(0.85 + 0.15\frac{S_2}{S_1}), \quad (17)$$

where:

D – thermal lag of the walling was determined by the formula:

$$D = R_1 \cdot S_1 + R_2 \cdot S_2 + ... + R_n \cdot S_n, \quad (18)$$

R_1, R_2, R_n – heat transfer resistances of separate layers of the walling;

S_1, S_2, S_n– designed u-value of material of separate layers, W/ m^2·°C, by app. 3 [8] S = 0.82 W/ m^2·°C;

For walls:

$$D = 1.82 \cdot 0.82 = 1.49;$$

$$V = 2^{1.49} \cdot (0.83 + 3\frac{1.82}{1.49})(0.85 + 0.15 \cdot 1) = 12.62 \text{ occations;}$$

For roof:

$$D = 2.24 \cdot 0.82 = 1.84;$$

$$V = 2^{1.84} \cdot (0.83 + 3\frac{2.24}{1.84})(0.85 + 0.15 \cdot 1) = 16.05 \text{ occations;}$$

Θ_1, Θ_2 – the coefficient considering harmonical temperature change of outdoor air, from table 6 [10];

ε – delay of temperature oscillation in walling was determined by the formula, h:

$$\varepsilon = 2.7D – 0.4, \quad (19)$$

Delay of temperature oscillation for wall:

$$\varepsilon = 2.7 \cdot 1.49 – 0.4 = 3.62 \text{ h;}$$

Delay of temperature oscillation for roof:

$$\varepsilon = 2.7 \cdot 1.84 – 0.4 = 4.57 \text{ h;}$$

A_{md} - the maximum daily range of temperature of outdoor temperature in July, °C, taken by [16], A_{md} = 19.6°C;

ρ - solar absorption coefficient by surface of walling, taken by app.7 [8], for facing white tile ρ = 0,45;

A_j - daily range of temperature of total solar radiation (direct and diffused solar radiation) W/ m^2, was determined by the formula:

$$A_j = J_{\max} - J_{aver}, \tag{20}$$

where:

$J_{\max}, J_{aver}$ - the maximum and average value of total solar radiation (direct and diffused solar radiation), arriving to the walling, taken from Table 7 and 8 [10], W/ m^2;

A_j for horizontal surfaces is presented in Table 7.

For 8 a.m. A_j = 559 – 319 = 240 W/ m^2 for 61° N.

Table 7 Total solar radiation for horizontal surfaces

Solar radiation, W/m^2							
Hours	5-6	6-7	7-8	8-9	9-10	10-11	11-12
	18-19	17-18	16-17	15-16	14-15	13-14	12-13
$J_{\max}$	216	328	446	559	649	720	769
J_{aver}	319	319	319	319	319	319	319
A_j	103	9	127	240	330	401	450

The maximum A_j = 450 W/ m^2.

A_j for vertical surfaces orientated to the North is presented in Table 8:

Table 8 Total solar radiation for vertical surfaces orientated to the North

Solar radiation, W/m^2							
Hours	5-6	6-7	7-8	8-9	9-10	10-11	11-12
	18-19	17-18	16-17	15-16	14-15	13-14	12-13
$J_{\max}$	227	133	77	73	70	69	67
J_{aver}	82	82	82	82	82	82	82
A_j	145	51	-5	-9	-12	-13	-15

The maximum A_j = 145 W/ m^2.

A_j for vertical surfaces orientated to the South is presented in Table 9.

Table 9 Total solar radiation for vertical surfaces orientated to the South

Solar radiation, W/m^2							
Hours	5-6	6-7	7-8	8-9	9-10	10-11	11-12
	18-19	17-18	16-17	15-16	14-15	13-14	12-13
$J_{\max}$	46	77	202	359	485	593	657
J_{aver}	204	204	204	204	204	204	204
A_j	-158	-127	-2	155	281	389	453

The maximum A_j = 453 W/ m^2.

A_j for vertical surfaces orientated to the Southeast is presented in Table 10. The maximum A_j = 499 W/ m^2. A_j for vertical surfaces orientated to the Southwest is presented in Table 11. The maximum A_j = 499 W/ m^2. A_j for vertical surfaces orientated to the Northeast is presented in Table 12. The maximum A_j = 451 W/ m^2. A_j for vertical surfaces orientated to the Northwest is presented in Table 13. The maximum A_j = 451 W/ m^2.

Table 10 Total solar radiation for vertical surfaces orientated to the Southeast

Solar radiation, W/m^2									
Hours	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
$J_{\max}$	21	111	277	492	642	712	706	647	549
J_{aver}	213	213	213	213	213	213	213	213	213
A_j	-192	-102	64	279	429	499	493	434	336
Hours	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21
$J_{\max}$	355	221	88	81	66	53	37	23	6
J_{aver}	213	213	213	213	213	213	213	213	213
A_j	142	8	-125	-132	-147	-160	-176	-190	-207

Table 11 Total solar radiation for vertical surfaces orientated to the Southwest

Solar radiation, W/m^2									
Hours	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
$J_{\max}$	6	23	37	53	66	81	88	221	355
J_{aver}	213	213	213	213	213	213	213	213	213
A_j	-207	-190	-176	-160	-147	-132	-125	8	142
Hours	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21
$J_{\max}$	549	647	706	712	642	492	277	111	21
J_{aver}	213	213	213	213	213	213	213	213	213
A_j	336	434	493	499	429	279	-213	-102	-192

Table 12 Total solar radiation for vertical surfaces orientated to the Northeast

Solar radiation, W/m^2									
Hours	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
$J_{\max}$	86	363	538	585	524	340	147	73	73
J_{aver}	134	134	134	134	134	134	134	134	134
A_j	-48	229	404	451	390	206	13	-61	-61
Hours	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21
$J_{\max}$	72	72	72	71	67	58	44	24	7
J_{aver}	134	134	134	134	134	134	134	134	134
A_j	-62	-62	-62	-63	-67	-76	-134	-110	-127

Table 13 Total solar radiation for vertical surfaces orientated to the Northwest

Solar radiation, W/m^2									
Hours	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
$J_{\max}$	7	24	44	58	67	71	72	72	72
J_{aver}	134	134	134	134	134	134	134	134	134
A_j	-127	-110	-90	-76	-67	-63	-62	-62	-62
Hours	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21

$J_{\max}$	73	73	147	340	524	585	538	363	86
J_{aver}	134	134	134	134	134	134	134	134	134
A_j	-61	-61	13	206	390	451	-134	229	-48

A_j for vertical surfaces orientated to the East is presented in table 14.

Table 14 Total solar radiation for vertical surfaces orientated to the East

Solar radiation, W/m^2							
Hours	5-6	6-7	7-8	8-9	9-10	10-11	11-12
$J_{\max}$	614	767	781	720	565	373	186
J_{aver}	206	206	206	206	206	206	206
A_j	408	561	575	514	359	167	-20
Hours	12-13	13-14	14-15	15-16	16-17	17-18	18-19
$J_{\max}$	76	72	69	67	62	54	41
J_{aver}	206	206	206	206	206	206	206
A_j	-130	-134	-137	-139	-144	-152	-165

The maximum $A_j =$ 575 W/ m^2.

A_j for vertical surfaces orientated to the West is presented in Table 15.

Table 15 Total solar radiation for vertical surfaces orientated to the West

Solar radiation, W/m^2							
Hours	5-6	6-7	7-8	8-9	9-10	10-11	11-12
$J_{\max}$	41	54	62	67	69	72	76
J_{aver}	206	206	206	206	206	206	206
A_j	-165	-152	-144	-139	-137	-134	-130
Hours	12-13	13-14	14-15	15-16	16-17	17-18	18-19
$J_{\max}$	186	373	565	720	781	767	614
J_{aver}	206	206	206	206	206	206	206
A_j	-20	167	359	514	575	561	408

The maximum A_j = 575 W/ m^2.

Table 16 Areas of the massive walling

	E	W	NE	SW	SE	N	NW	S
A,m^2	1816.9	2066.3	2153.9	2438.1	27.6	403.7	355	405.6

The receipt of heat flow through exterior wall delays for 3.62 hours, in comparison with the receipt of the maximum of heat flow on a vertical surface in 15 hours, so the maximum flow of heat through the wall will be at 15 + 3,62 ≅ 18,62 hours at Θ_1=1, which in table. 6 [10] is located at the intersection of line 19 and graph 19. In comparison with the receipt of the maximum of heat flow on a vertical surface in 7 hours, so the maximum flow of heat through the wall will be at 7+3,62 ≅ 10,62 hours at Θ_1=1, which in table. 6 [10] is located at the intersection of line 11 and graph 11. Similarly for West orientated vertical surface at 16 hours, so 16+3,62 ≅ 19,62 hours at Θ_2=1, which is located at the intersection of line 20 and graph 20. Similarly for Northeast orientated vertical surface at 6 hours, so 6+3,62 ≅ 9,62 hours at Θ_2=1, which is located at the intersection of line 10 and graph 10. Similarly for Southwest orientated vertical surface at 15 hours, so 15+3,62 ≅ 18,62 hours at Θ_2=1, which is located at the intersection of line 19 and graph 19. Similarly for Southeast orientated vertical surface at 15 hours, so 8+3,62 ≅ 11,62 hours at Θ_2=1, which is located at the intersection of line 12 and graph 12. Similarly for North orientated vertical surface at 5 hours, so 5+3,62 ≅ 8,62 hours at Θ_2=1, which is located at the intersection of line 9 and graph 9. Similarly for Northwest orientated vertical surface at 17 hours, so 17+3,62 ≅ 20,62 hours at Θ_2=1, which is located at the intersection of line 21 and graph 21. Similarly for South orientated vertical surface at 11 hours, so 11+3,62 ≅ 14,62 hours at Θ_2=1, which is located at the intersection of line 15 and graph 15.

The receipt of heat flow through the roof delays for 4.57 hours, in comparison with the receipt of the maximum of heat flow on a vertical surface in 15 hours, so the maximum flow of heat through the roof will be at 15 + 4,57 ≅ 19,57 hours at Θ_1=1, which in table. 6 [10] is located at the intersection of line 20 and graph 20. In comparison with the receipt of the maximum of heat flow on horizontal surface in 11 hours, so the maximum flow of heat through the roof will be at 11+4,57 ≅ 15,57 hours at Θ_2=1, which in table. 6 [10] is located at the intersection of line 16 and graph 16.

The results of calculation of heat flows are shown in Tables 17 and 18.

Heat flow Q_m for walling oriented to the East at 9 a.m.:

$$Q_{m,i}=\left[\frac{1}{1.82}0.45\frac{206}{23}+\frac{1\cdot 8.7}{12.62}(0.5(-0.87)19.6+\frac{0.45}{23}\cdot 0.87\cdot 575)\right]1816.9= .$$

$$=5600W;$$

Heat flow Q_m for horizontal walling at 9 a.m.:

$$Q_{m,i}=\left[\frac{1}{2.24}0.45\frac{319}{23}+\frac{1\cdot 8.7}{16.05}(0.5(-0.97)19.6+\frac{0.45}{23}\cdot(-0.26)\cdot 450)\right]8312= .$$

$$=-29986W;$$

Total heat flows are shown in Table 19.

The maximum heat gain from solar radiation through the walling is observed from 17 to 18 hours:

Q = 224.3 kW (design value).

Table 17 Heat flow through vertical walling

Heat flow Q_m for East orientated walling , kW								
Hours	1	2	3	4	5	6	7	8
Θ_1	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00	-0.97
Θ_2	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50	0.71
Q_m	-8.24	-9.17	-9.16	-8.36	-6.66	-4.22	-1.21	2.12
Hours	9	10	11	12	13	14	15	16
Θ_1	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50	0.71
Θ_2	0.87	0.97	1.00	0.97	0.87	0.71	0.50	0.26
Q_m	5.60	8.98	11.98	14.50	16.28	17.22	17.21	16.40
Hours	17	18	19	20	21	22	23	24
Θ_1	0.87	0.97	1.00	0.97	0.87	0.71	0.50	0.26
Θ_2	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00	-0.97
Q_m	14.70	12.27	9.25	5.93	2.44	-0.93	-3.93	-6.45

Heat flow Q_m for West orientated walling , kW								
Hours	1	2	3	4	5	6	7	8
Θ_2	0.26	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00
Q_m	8.74	0.95	-6.57	-13.35	-18.95	-22.91	-24.93	-24.99
Hours	9	10	11	12	13	14	15	16
Θ_2	-0.97	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50
Q_m	-23.11	-19.28	-13.78	-7.07	0.41	8.21	15.72	22.50
Hours	17	18	19	20	21	22	23	24
Θ_2	0.71	0.87	0.97	1.00	0.97	0.87	0.71	0.50
Q_m	28.10	32.06	34.08	34.14	32.27	28.43	22.93	16.22
Heat flow Q_m for Northeast orientated walling , kW								
Hours	1	2	3	4	5	6	7	8
Θ_2	-0.71	-0.50	-0.26	0.00	0.26	0.50	0.71	0.87
Q_m	-6.20	-7.23	-7.58	-7.23	-6.15	-4.46	-2.15	0.39
Hours	9	10	11	12	13	14	15	16
Θ_2	0.97	1.00	0.97	0.87	0.71	0.50	0.26	0.00
Q_m	3.15	5.87	8.54	10.72	12.41	13.44	13.79	13.43
Hours	17	18	19	20	21	22	23	24
Θ_2	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00	-0.97	-0.87
Q_m	12.36	10.67	8.35	5.82	3.05	0.33	-2.33	-4.51
Heat flow Q_m for Southwest orientated walling , kW								
Hours	1	2	3	4	5	6	7	8
Θ_2	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00	-0.97
Q_m	5.58	-2.97	-10.86	-17.76	-23.02	-26.31	-27.30	-26.31
Hours	9	10	11	12	13	14	15	16
Θ_2	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50	0.71
Q_m	-23.02	-17.76	-10.86	-2.97	5.58	14.13	22.02	28.93
Hours	17	18	19	20	21	22	23	24
Θ_2	0.87	0.97	1.00	0.97	0.87	0.71	0.50	0.26
Q_m	34.19	37.48	38.46	37.48	34.19	28.93	22.02	14.13
Heat flow Q_m for Southeast orientated walling , kW								

Hours	1	2	3	4	5	6	7	8
Θ_2	-0.97	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50
Q_m	-0.12	-0.15	-0.16	-0.16	-0.15	-0.12	-0.07	-0.02
Hours	9	10	11	12	13	14	15	16
Θ_2	0.71	0.87	0.97	1.00	0.97	0.87	0.71	0.50
Q_m	0.03	0.09	0.15	0.20	0.24	0.27	0.29	0.29
Hours	17	18	19	20	21	22	23	24
Θ_2	0.26	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00
Q_m	0.27	0.24	0.20	0.15	0.09	0.03	-0.02	-0.07

Heat flow Q_m for North orientated walling , kW

Hours	1	2	3	4	5	6	7	8
Θ_2	-0.50	-0.26	0.00	0.26	0.50	0.71	0.87	0.97
Q_m	-0.04	-0.56	-1.01	-1.38	-1.62	-1.73	-1.68	-1.52
Hours	9	10	11	12	13	14	15	16
Θ_2	1.00	0.97	0.87	0.71	0.50	0.26	0.00	-0.26
Q_m	-1.23	-0.81	-0.32	0.21	0.75	1.27	1.72	2.09
Hours	17	18	19	20	21	22	23	24
Θ_2	-0.50	-0.71	-0.87	-0.97	-1.00	-0.97	-0.87	-0.71
Q_m	2.33	2.44	2.40	2.24	1.94	1.53	1.03	0.50

Heat flow Q_m for Northwest orientated walling , kW

Hours	1	2	3	4	5	6	7	8
Θ_2	0.50	0.26	0.00	-0.26	-0.50	-0.71	-0.87	-0.97
Q_m	1.59	0.45	-0.69	-1.75	-2.65	-3.35	-3.77	-3.91
Hours	9	10	11	12	13	14	15	16
Θ_2	-1.00	-0.97	-0.87	-0.71	-0.50	-0.26	0.00	0.26
Q_m	-3.73	-3.29	-2.57	-1.65	-0.57	0.57	1.71	2.78
Hours	17	18	19	20	21	22	23	24
Θ_2	0.50	0.71	0.87	0.97	1.00	0.97	0.87	0.71
Q_m	3.68	4.37	4.79	4.93	4.76	4.31	3.59	2.67

Heat flow Q_m for South orientated walling , kW

Hours	1	2	3	4	5	6	7	8

Θ_2	-0.87	-0.97	-1.00	-0.97	-0.87	-0.71	-0.50	3.75
Q_m	-1.27	-2.23	-2.96	-3.46	-3.65	-3.53	-3.09	7.51
Hours	9	10	11	12	13	14	15	16
Θ_2	0.00	0.26	0.50	0.71	0.87	0.97	1.00	0.97
Q_m	-1.49	-0.41	0.76	1.94	3.05	4.01	4.74	5.24
Hours	17	18	19	20	21	22	23	24
Θ_2	0.87	0.71	0.50	0.26	0.00	-0.26	-0.50	-0.71
Q_m	5.43	5.31	4.87	4.19	3.27	2.19	1.02	-0.16

Table 18 Heat flow through horizontal walling

Heat flow Q_m for roof, kW								
Hours	1	2	3	4	5	6	7	8
Θ_1	0.26	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00
Θ_2	-0.71	-0.87	-0.97	-1.00	-0.97	-0.87	-0.71	-0.50
Q_m	6.48	-11.35	-26.80	-38.59	-46.67	-49.77	-47.83	-40.83
Hours	9	10	11	12	13	14	15	16
Θ_1	-0.97	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50
Θ_2	-0.26	0.00	0.26	0.50	0.71	0.87	0.97	1.00
Q_m	-29.9	-15.3	2.12	20.9	39.84	57.67	73.12	84.91
Hours	17	18	19	20	21	22	23	24
Θ_1	0.71	0.87	0.97	1.00	0.97	0.87	0.71	0.50
Θ_2	0.97	0.87	0.71	0.50	0.26	0.00	-0.26	-0.50
Q_m	92.99	96.09	94.15	87.15	76.3	61.6	44.2	25.4

Table 19 Total heat flow through the walling

Heat flow Q_m through the windows, kW								
Hours	1	2	3	4	5	6	7	8
Q_m								21.03
Hours	9	10	11	12	13	14	15	16
Q_m	21.03	14.51	12.80	13.91	23.11	29.46	33.95	34.20
Hours	17	18	19	20	21	22	23	24

Q_m	30.20							
Heat flow Q_m through the walls, kW								
Hours	1	2	3	4	5	6	7	8
Q_m	0.06	-20.91	-38.98	-53.45	-62.85	-66.62	-64.19	-46.74
Hours	9	10	11	12	13	14	15	16
Q_m	-43.81	-26.61	-6.11	15.88	38.15	59.12	77.19	91.66
Hours	17	18	19	20	21	22	23	24
Q_m	101.1	104.8	102.4	94.88	82.02	64.82	44.32	22.32
Heat flow Q_m through the roof, kW								
Hours	1	2	3	4	5	6	7	8
Q_m	6.48	-11.35	-26.80	-38.59	-46.67	-49.77	-47.83	-40.83
Hours	9	10	11	12	13	14	15	16
Q_m	-29.9	-15.3	2.12	20.9	39.84	57.67	73.12	84.91
Hours	17	18	19	20	21	22	23	24
Q_m	92.99	96.09	94.15	87.15	76.3	61.6	44.2	25.4
Total heat flow Q_m through the walling, kW								
Hours	1	2	3	4	5	6	7	8
Q_m	6.53	-32.26	-65.78	-92.03	-109.5	-116.4	-112.0	-66.53
Hours	9	10	11	12	13	14	15	16
Q_m	-59.28	-29.06	9.93	54.01	101.1	146.3	184.8	210.8
Hours	17	18	19	20	21	22	23	24
Q_m	224.3	200.9	196.6	182	158.3	126.4	88.51	47.73

4.11 General heat gain

Total heat gain is shown in Table 20.

Table 20 Total heat gain

Heat gain, kW	Period	
	Warm	Cold
Heat gain from athletes	43.50	43.50
Heat gain through the outer shell	293.55	-358.23

Heat gain from solar radiation	224.30	0.00
Heat gain from artificial lighting	113.32	113.32
Heat gain by infiltration	6.49	-13.04
∑Q, kW	701.16	-214.45

4.12 Calculation of air exchange in the cold period

According to p.8.1.3 [17] the necessary amount of supply air is determined by calculation for assimilation of excess heat, however, the inflow of outside air should not be less than 80 m^2/h for 1 athlete.

The required amount of fresh air for athletes [18]:

$$L_{fr} = N \cdot m \,, \tag{21}$$

where:

N – the amount of athletes;

m – the required specific supply airflow for 1 athlete, m = 80 m^3/h;

$$L_{fr} = 150 \cdot 80 = 12000 \text{ m}^3/\text{h}.$$

Air exchange for heating was determined by the formula (app. I [19]):

$$\mathrm{L} = \frac{3.6 \sum \mathrm{Q}_{\mathrm{exc}}}{\mathrm{c} \cdot \rho (\mathrm{t}_{\mathrm{l}} - \mathrm{t}_{\mathrm{in}})}, \tag{22}$$

where:

$\sum Q_{exc}$ – excess heat, W;

c – air heat capacity , c = 1.006 kJ/(kg·˚C);

ρ – density of air, ρ = 1.2 kg/m^3;

t_l – temperature of the air removed from the premise,˚C;

t_{in} – temperature of fresh air, ˚C;

For cold period:

L = 40200 m3/h (designed value);

$$\mathrm{L}_h = \frac{3.6 \cdot (-214450)}{1.2 \cdot 1.006 (-5 - \mathrm{t}_{\mathrm{in}})} = 40200 \text{ m}^3/\text{h} \Rightarrow \mathrm{t}_{\mathrm{in}} = +10 \text{ ˚C}.$$

The processes on Mollier diagram (see Appendix 1):

Point E – parameters of external air;

Point S – parameters of supply air;

Point I – parameters of internal air;

Point M – parameters of mixture of internal and external air;

The proportion of fresh and recirculated air is regulated in mixing chamber in accordance with sanitary requirements.

The quantity of recirculated air:

$$L_{rec} = L_h - L_{fr}\ , \tag{23}$$

$$L_{rec} = 40200 - 12000 = 28200\ m^3/h;$$

The temperature of the mixture (point M) is determined by the formula:

$$t_m = \frac{M_1 t_1 + M_2 t_2}{M_1 + M_2}, \tag{24}$$

where:

M_1, M_2 – mass of the mixed air flows, M_1=12000 m^3/h, M_2 = 28200 m^3/h;

t_1, t_2 – temperature of the mixed air flows, t_1= - 41˚C, t_2= -5 ˚C;

$$t_m = \frac{12000 \cdot (-41) + 28200 \cdot (-5)}{12000 + 28200} = -15.7˚C.$$

Ɛ – temperature-humidity coefficient describes the process of change of state of air, determined by the formula:

$$Ɛ = \frac{3600 \sum Q}{\sum W}, \tag{25}$$

where:

Q – surplus heat, W;

W – excess moisture, kg/h;

$$Ɛ = \frac{3600\,(-214.45)}{16.5} = -46789.$$

4.13 Calculation of air exchange in the warm period

As in the ventilation plant supply air is not cooled, the removal of excess heat from the tunnel by using the air-coolers. The airflow from the local air-coolers is sent to the zone of the discharge air duct, so the temperature of the receding air is not increased and is not more than -5˚C.

Part of the excess heat in the warm period of the supply air is removed by mixing fresh air with the recirculated (cold) air, the remaining part of the excess heat is removed by air-coolers.

The processes on Mollier diagram (see Appendix 2):

The temperature of the mixture (point M) is determined by the formula (24):

$$t_m = \frac{12000 \cdot 22.7 + 28200 \cdot (-5)}{12000 + 28200} = +3.3\ ˚C.$$

Temperature-humidity coefficient describes the process of change of state of air, determined by the formula (25):

$$\varepsilon = \frac{3600 \cdot 701.16}{16.5} = 152980.$$

The heat demand on the equipment of the ventilation system was determined by the formla ("Guidelines "Calculation of air conditioning systems"" T. M. Klimchuk):

$$Q_{vent} = \rho \cdot L \cdot \Delta I, \qquad (26)$$

where:

ρ – air density, ρ = 1.2 kg/m^3;

L – air exchange, m^3/h , L = 40200 m^3/h;

ΔI – the difference between the enthalpies at the inlet and the outlet of the apparatus (the enthalpy of the mixture and supply air flow), m^3/h;

$$\Delta I = 15.2-(-2)) = 17.2 \text{ kJ/kg},$$

$$Q_{vent} = 1.2 \cdot 40200 \cdot 17.2 = 829728 \text{ kJ/h} = 230.48 \text{ kW}.$$

Taking into account heat gain from the operation of the ventilation system during the warm period, the total heat gain:

$$Q = \sum Q_{exc} + Q_{vent}, \qquad (27)$$

$$Q = 701.16 + 230.48 = 931.64 \text{ kW}.$$

For providing air-distribution equitability and ensure the required air speed in the working area requires air coolers with specification: air exchange L = 6400 m^3/h, cold-productivity Q = 8542 W at temperature difference Δt = 4˚C.

The number of air coolers was determined from the formula (22):

$$L = \frac{3.6 \cdot 931640}{1.2 \cdot 1.006 \cdot 4} = 694563 \text{ m}^3\text{/h},$$

Inasmuch as air exchange of one air cooler equals L = 6400 m^3/h, the number of discharge air ducts:

$$N = L_{com}/L = 694563/6400 = 108{,}5 = 109 \text{ units}.$$

5 CALCULATION OF THE SECTION

Choose the section in the axes 2/1-3/1. Length 36 m, the section is 0,053 part of the total volume of the track.

5.1 Calculation of moisture gain of the section

Moisture gain from athletes was defined by the formula, g/h:

$$W = n \cdot m \cdot 0{,}053\ , \tag{28}$$

where:

n – the amount of people;

m – the amount of moisture emitted by one adult (male), g/h;

$$W = 150 \cdot 110 \cdot 0.053 = 874.5 \text{ g/h}.$$

5.2 Calculation of heat gain from athletes of the section

Heat gain from athletes was determined by the formula, W:

$$Q_p = n \cdot q_p \cdot 0{,}053, \tag{29}$$

where:

Q_p – the amount of heat;

n – the amount of people;

q_p – the amount of heat generation emitted by one adult (male), g/h, depends on the temperature of the internal air and the category of works (for heavy work, the indoor temperature - 5°C, $q_p = 290$ W according to table 9 [10]).

$$Q_p = 150 \cdot 290 \cdot 0.053 = 2.306 \text{ kW}.$$

5.3 Calculation of heat gain from artificial lighting of the section

Heat generations from artificial lighting were determined by the formula, W:

$$Q_{\text{light}} = E \cdot A \cdot q_{\text{light}} \cdot h_{\text{light}} \cdot 0{,}053, \tag{30}$$

where:

q_{light} – average specific heat generation of the lamps, $q_{\text{light}} = 0.094$ W/lx·m^2 (for a floor area more than 200 m^2 and a height more than 4.2 m);

A – floor area, m^2;

E – level of illumination in the room space, E = 500 lx (according to [11]);

h_{light} – the coefficient considering the placement of the lamp $h_{\text{light}} = 1$ (directly in the room);

$$Q_{\text{light}} = 500 \cdot 8037 \cdot 0{,}094 \cdot 1 \cdot 0.053 = 20 \text{ kW},$$

$$Q_{\text{light .design}} = 20 \cdot 30\% = 6.01 \text{ kW}.$$

5.4 Calculation of heat loss through the outer shell in the cold period of the section

Heat gain through the outer shell were determined by the formula (7), W:

Area of the window:

$S_{wind} = 48 \cdot 0.54 = 25.92$ m^2;

Area of the walls:

$S_{wall} = 8.2 \cdot 36 + 6.6 \cdot 36 - 25.92 = 506.88$ m^2;

Area of the roof:

$S_r = 12.1 \cdot 36 = 435.6$ m^2;

$$Q_{shell} = (506.88 \cdot 0.549 + 435.6 \cdot 0.446 + 25.92 \cdot 2) \cdot (-41-(-5)) = -18.88 \text{ kW}.$$

5.5 Calculation of heat loss by infiltration in the cold period of the section

The firing rate Q_i, W, for heating the infiltrated air was determined by the formula (8).

Specific gravity, N/m^3, of outside air and air in the building with the temperature t °C was determined by the formula (11):

$$\gamma_{in} = 3463/(273-5) = 12.9 \text{ N/m}^3;$$

$$\gamma_{out} = 3463/(273-41) = 14.9 \text{ N/m}^3;$$

Density of the outside air, kg /m^3, was determined by the formula (12):

$$\rho_{out} = 14.9 / 9.81 = 1.52 \text{ kg /m}^3;$$

Calculated pressure difference between the outer and inner surfaces of the outer shells, daPa, was determined by the formula (10):

$$\Delta p = 1.5(14.9 - 12.9) + 0.5 \cdot 6.9^2 \cdot 1.52(0.8 + 0.6)1 - 0 = 72.5Pa = 7{,}25$$ daPa;

The amount of the infiltrated air , kg/h, through the fencing of the room space was determined by the formula (9):

$$\sum G_i = \frac{25.92 \cdot 7.25^{0.67}}{0.29} = 336.96\,\text{kg/h} = 0.0936\ \text{kg/s}$$,

Q$_i$ = 0.28·0.0936 ·0.8 ·1 ·(-41+5) = -0.755 kW.

5.6 Calculation of heat gain through the outer shell in the warm period of the section

Heat gain through the outer shell was determined by the formula (7):

Q$_{orp}$ = (506.88·0.549+435.6·0.446+25.92·2)·(22.7-(-5)) = 14.53 kW.

5.7 Calculation of heat gain by infiltration in the warm period of the section

The firing rate Q$_i$, W, for cooling the infiltrated air was determined by the formula (8).

Specific gravity, N/m^3, of outside air and air in the building was determined by formula (11):

γ_{out} = 3463/(273-5) = 12.9 N/m^3;

γ_{in} = 3463/(273+22,7) = 11.7 N/m^3;

According to formula (12), density of the outside air:

ρ_{out} = 11.7/9.81 = 1.19 kg/m^3;

According to formula (10), calculated pressure difference between the outer and inner surfaces of the outer shells:

$$\Delta p = 1.5(11.7 - 12.9) + 0.5 \cdot 6.9^2 \cdot 1.19(0.8 + 0.6)1 - 0 = 37.9Pa =$$
$$= 3.79daPa;$$

According to formula (9) the amount of the infiltrated air, kg/h, through the fencing of the room space:

$$\sum G_i = \frac{25.92 \cdot 3.79^{0.67}}{0.29} = 217.99\,\text{kg/h} = 0.061\ \text{kg/s}$$,

Q$_i$ = 0.28 ·0.061 ·0.8 ·1 ·(22.7+5) = 0.376 kW .

5.8 Calculation of heat gain from solar radiation through the light apertures in the warm period of the section

Heat flow, W, from solar radiation through the light apertures was calculated by the formula (13). The area of one window A_{gl1} = 0.54 m^2 (0.9 m * 0.6 m), all windows are the same. The amount of light apertures n = 48, all windows are oriented to the East.

A_{gl} – the area of the light apertures (the glasses), m^2, was determined by formula (15):

$$A_{gl} = 0.54 \cdot 48 = 25.92 \text{ m}^2;$$

The calculation of the heat gain from solar radiation through the light apertures from 8 to 9 a.m.:

$$Q_E = 608 \cdot 0.95 \cdot 0.80 \cdot 0.296 \cdot 0.54 \cdot 48 = 3545 \text{ W}.$$

The results of calculation of heat gain from solar radiation through light apertures are presented in Table 21.

Table 21 The heat gain from solar radiation through light apertures

Current hour	q, W/m^2	Q, W
8-9	608	3545
9-10	455	2653
10-11	258	1504
11-12	97	566
12-13	56	327
13-14	53	309
14-15	51	297
15-16	50	292
16-17	45	262
17-18	40	233

5.9 Calculation of heat gain from solar radiation through the massive walling in the warm period of the section

Heat flow, W, from solar radiation through the massive walling was calculated by the formula (16).

Thermal lag of vertical walling was determined by the formula (18):

$$D = 1{,}82 \cdot 0{,}82 = 1{,}49;$$

Thermal lag of horizontal walling was determined by the formula (18):

$$D = 2{,}24 \cdot 0{,}82 = 1{,}84;$$

Value of outdoor temperature oscillation damping in vertical walling was determined by the formula (17):

$$V = 2^{1.49} \cdot (0.83 + 3\frac{1.82}{1.49})(0.85 + 0.15 \cdot 1) = 12.62 \text{ occations;}$$

Value of outdoor temperature oscillation damping in horizontal walling was determined by the formula (17):

$$V = 2^{1.84} \cdot (0.83 + 3\frac{2.24}{1.84})(0.85 + 0.15 \cdot 1) = 16.05 \text{ occations;}$$

Delay of temperature oscillation in vertical walling was determined by the formula (19), h:

$$\varepsilon = 2.7 \cdot 1.49 - 0.4 = 3.62 \text{ h;}$$

Delay of temperature oscillation in horizontal walling was determined by the formula (19), h:

$$\varepsilon = 2.7 \cdot 1.84 - 0.4 = 4.57 \text{ h;}$$

Daily range of temperature of total solar radiation (direct and diffused solar radiation) W/ m^2, was shown in Tables 7,8;

Table 22 Area of massive walling

	E	W
A, m^2	237.6	270

The receipt of heat flow through exterior wall delays for 3.62 hours, in comparison with the receipt of the maximum of heat flow on a vertical surface in 15 hours, so the maximum flow of heat through the wall will be at 15 + 3,62 ≅ 18,62 hours at Θ_1=1, which in table. 6 [10] is located at the intersection of line 19 and graph 19. In comparison with the receipt of the maximum of heat flow on a vertical surface in 7 hours, so the maximum flow of heat through the wall will be at 7+3,62 ≅ 10,62 hours at Θ_1=1, which in table. 6 [10] is located at the intersection of line 11 and graph 11. Similarly for West orientated vertical surface at 16 hours, so 16+3,62 ≅ 19,62 hours at Θ_2=1, which is located at the intersection of line 20 and graph 20.

The receipt of heat flow through the roof delays for 4.57 hours, in comparison with the receipt of the maximum of heat flow on a vertical surface in 15 hours, so the maximum flow of heat through the roof will be at 15 + 4,57 ≅ 19,57 hours at Θ_1=1, which in table. 6 [10] is located at the intersection of line 20 and graph 20. In comparison with the receipt of the maximum of heat flow on horizontal surface in 11 hours, so the maximum flow of heat through the roof will be at 11+4,57 ≅ 15,57 hours at Θ_2=1, which in table. 6 [10] is located at the intersection of line 16 and graph 16.

The results of calculation of heat flows are shown in Tables 17 and 18.

Heat flow Q_m for walling oriented to the East at 9 a.m.:

$$Q_{m,i} = \left[\frac{1}{1.82} 0.45 \frac{206}{23} + \frac{1 \cdot 8.7}{12.62} (0.5(-0.87)19.6 + \frac{0.45}{23} \cdot 0.87 \cdot 575) \right] 1816.9 =$$
$$= 5600W;$$

Heat flow Q_m for horizontal walling at 9 a.m.:

$$Q_{m,i} = \left[\frac{1}{2.24} 0.45 \frac{319}{23} + \frac{1 \cdot 8.7}{16.05} (0.5(-0.97)19.6 + \frac{0.45}{23} \cdot (-0.26) \cdot 450) \right] 8312 =$$
$$= -29986W;$$

Heat flows for walls are presented in Table 23, Heat flows for roof are presented in Table 24.

Heat flow Q_m for walling oriented to the East at 9 a.m.:

$$Q_{m,i} = \left[\frac{1}{1.82} 0.45 \frac{206}{23} + \frac{1 \cdot 8.7}{12.62} (0.5(-0.87)19.6 + \frac{0.45}{23} \cdot 0.87 \cdot 575) \right] 237.6 = 730W;$$

Heat flow Q_m for horizontal walling at 9 a.m.:

$$Q_{m,i} = \left[\frac{1}{2.24} 0.45 \frac{319}{23} + \frac{1 \cdot 8.7}{16.05} (0.5(-0.97)19.6 + \frac{0.45}{23} \cdot (-0.26) \cdot 450) \right] 435.6 = -1570W;$$

Total heat flows are shown in Table 25.

The maximum heat gain from solar radiation through the walling is observed from 17 to 18 hours:

Q = 10.83 kW (design value).

Table 23 Heat flow through vertical walling

Heat flow Q_m for East orientated walling , kW								
Hours	1	2	3	4	5	6	7	8
Θ_1	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00	-0.97
Θ_2	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50	0.71
Q_m	-1.08	-1.20	-1.20	-1.09	-0.87	-0.55	-0.16	0.28
Hours	9	10	11	12	13	14	15	16
Θ_1	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50	0.71
Θ_2	0.87	0.97	1.00	0.97	0.87	0.71	0.50	0.26
Q_m	0.73	1.17	1.57	1.90	2.13	2.25	2.25	2.14
Hours	17	18	19	20	21	22	23	24
Θ_1	0.87	0.97	1.00	0.97	0.87	0.71	0.50	0.26
Θ_2	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00	-0.97
Q_m	1.92	1.60	1.21	0.77	0.32	-0.12	-0.51	-0.84
Heat flow Q_m for West orientated walling , kW								
Hours	1	2	3	4	5	6	7	8
Θ_2	0.26	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00
Q_m	1.14	0.12	-0.86	-1.74	-2.48	-2.99	-3.26	-3.27
Hours	9	10	11	12	13	14	15	16
Θ_2	-0.97	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50
Q_m	-3.02	-2.52	-1.80	-0.92	0.05	1.07	2.05	2.94
Hours	17	18	19	20	21	22	23	24
Θ_2	0.71	0.87	0.97	1.00	0.97	0.87	0.71	0.50
Q_m	3.67	4.19	4.45	4.46	4.22	3.71	3.00	2.12

Table 24 Heat flow through horizontal walling

Heat flow Q_m for roof, kW								
Hours	1	2	3	4	5	6	7	8
Θ_1	0.26	0.00	-0.26	-0.50	-0.71	-0.87	-0.97	-1.00
Θ_2	-0.71	-0.87	-0.97	-1.00	-0.97	-0.87	-0.71	-0.50
Q_m	0.34	-0.59	-1.40	-2.02	-2.45	-2.61	-2.51	-2.14
Hours	9	10	11	12	13	14	15	16

Θ_1	-0.97	-0.87	-0.71	-0.50	-0.26	0.00	0.26	0.50
Θ_2	-0.26	0.00	0.26	0.50	0.71	0.87	0.97	1.00
Q_m	-1.57	-0.80	0.11	1.10	2.09	3.02	3.83	4.45
Hours	17	18	19	20	21	22	23	24
Θ_1	0.71	0.87	0.97	1.00	0.97	0.87	0.71	0.50
Θ_2	0.97	0.87	0.71	0.50	0.26	0.00	-0.26	-0.50
Q_m	4.87	5.04	4.93	4.57	4.00	3.23	2.32	1.33

Table 25 Total heat flow through the walling

Heat flow Q_m through the windows, kW								
Hours	1	2	3	4	5	6	7	8
Q_m								3.55
Hours	9	10	11	12	13	14	15	16
Q_m	2.65	1.50	0.57	0.33	0.31	0.30	0.29	0.26
Hours	17	18	19	20	21	22	23	24
Q_m	0.23							
Heat flow Q_m through the walls, kW								
Hours	1	2	3	4	5	6	7	8
Q_m	0.07	-1.08	-2.06	-2.84	-3.35	-3.55	-3.42	-2.99
Hours	9	10	11	12	13	14	15	16
Q_m	-2.29	-1.35	-0.23	0.97	2.18	3.32	4.30	5.09
Hours	17	18	19	20	21	22	23	24
Q_m	5.59	5.79	5.66	5.24	4.54	3.59	2.48	1.28
Heat flow Q_m through the roof, kW								
Hours	1	2	3	4	5	6	7	8
Q_m	0.34	-0.59	-1.40	-2.02	-2.45	-2.61	-2.51	-2.14
Hours	9	10	11	12	13	14	15	16
Q_m	-1.57	-0.80	0.11	1.10	2.09	3.02	3.83	4.45
Hours	17	18	19	20	21	22	23	24
Q_m	4.87	5.04	4.93	4.57	4.00	3.23	2.32	1.33
Total heat flow Q_m through the walling, kW								
Hours	1	2	3	4	5	6	7	8

Q_m	0.40	-1.67	-3.46	-4.86	-5.79	-6.15	-5.92	-1.58
Hours	9	10	11	12	13	14	15	16
Q_m	-1.21	-0.64	0.45	2.40	4.58	6.65	8.43	9.79
Hours	17	18	19	20	21	22	23	24
Q_m	10.70	10.83	10.60	9.80	8.53	6.82	4.80	2.61

5.10 General heat gain

Total heat gain is shown in Table 26.

Table 26 Total heat gain

Heat gain, kW	Period	
	Warm	Cold
Heat gain from athletes	2.306	2.306
Heat gain through the outer shell	14.53	-18.88
Heat gain from solar radiation	10.83	0
Heat gain from artificial lighting	6.01	6.01
Heat gain by infiltration	0.376	-0.755
∑Q, kW	34.052	-11.319

5.11 Calculation of air exchange in the cold period of the section

According to p.8.1.3 [17], the necessary amount of supply air is determined by calculation for assimilation of excess heat, however, the inflow of outside air should not be less than 80 m^2/h for 1 athlete.

The required amount of fresh air for athletes:

$$L_{fr} = N \cdot m \cdot 0.053 \ , \tag{31}$$

where:

N – the amount of athletes;

m – the required specific supply airflow for 1 athlete, m = 80 m^3/h;

$$L_{fr} = 150 \cdot 80 \cdot 0.053 = 636 \ m^3/h.$$

Air exchange for heating was determined by the formula (22):

$$L = \frac{3.6*(-11319)}{1.2 \cdot 1.006(10-(-5))} = 2250 \ m^3/h \ .$$

5.12 Calculation of air exchange in the warm period of the section

As in the ventilation plant supply air is not cooled, the removal of excess heat from the tunnel by using the air-coolers. The airflow from the local air-coolers is sent to the zone of the discharge air duct, so the temperature of the receding air is not increased and is not more than -5˚C.

Part of the excess heat in the warm period of the supply air is removed by mixing fresh air with the recirculated (cold) air, the remaining part of the excess heat is removed by air-coolers.

The heat demand on the equipment of the ventilation system was determined by the formula (26):

$$Q_{vent} = 1.2 \cdot 2250 \cdot 17.2 = 46440 \text{ kJ/h} = 12.9 \text{ kW};$$

Total heat gain was determined by the formula (27):

$$Q = 34.052+12.9 = 46.952 \text{ kW};$$

For providing air-distribution equitability and ensure the required air speed in the working area requires air coolers with specification: air exchange $L = 6400$ m^3/h, cold-productivity $Q = 8542$ W at temperature difference $\Delta t = 4$˚C.

The number of air coolers was determined from the formula (22):

$$L = \frac{3.6 \cdot 46952}{1.2 \cdot 1.006 \cdot 4} = 35004 \text{ m}^3\text{/h},$$

Inasmuch as air exchange of one air cooler equals $L = 6400$ m^3/h, the number of discharge air ducts:

$$N = L_{com}/L = 35004/6400 = 5.5 = 6 \text{ units}.$$

6 NUMERICAL MODELING OF TUNNEL SECTION

To clarify supply air distribution and to compliance the required parameters of the internal air in the tunnel, method of numerical modeling was applied in the AnsysFluent software [20, 21].

The geometry of the tunnel section is presented in Figure 5.

Define border conditions, Figures 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16.

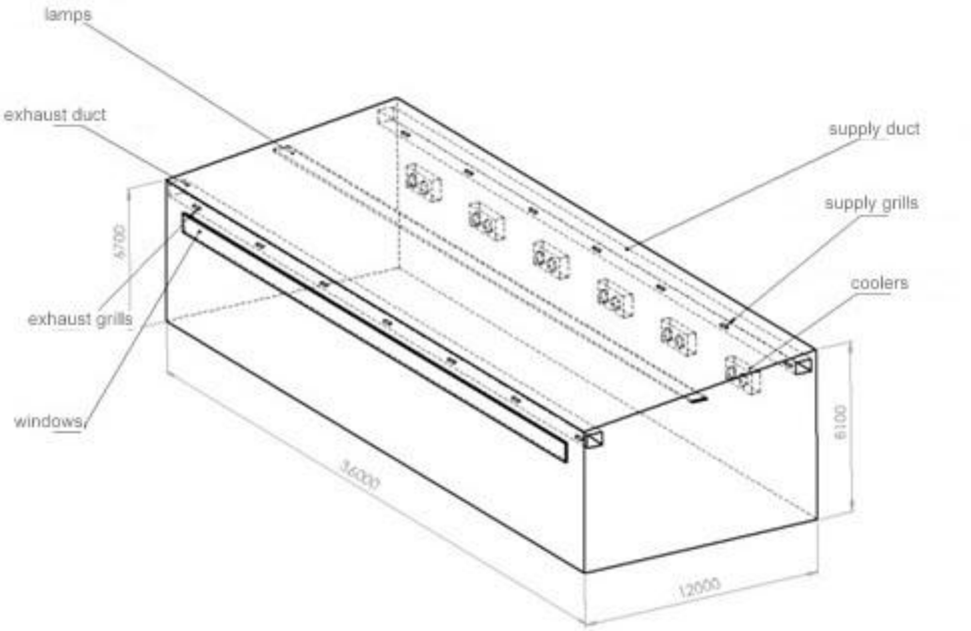


Figure 5. Geometry of the tunnel section

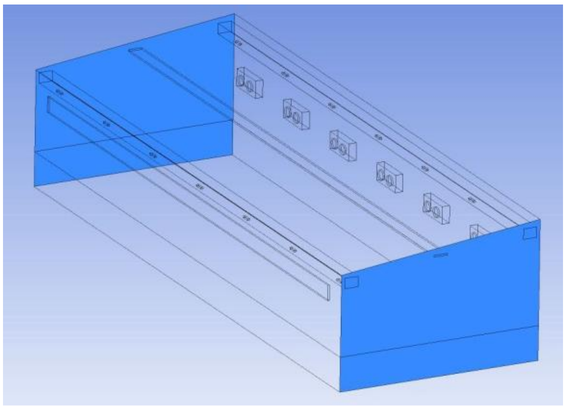


Figure 6. Border conditions for butt-end surfaces

For butt-end surfaces set adiabatic conditions.

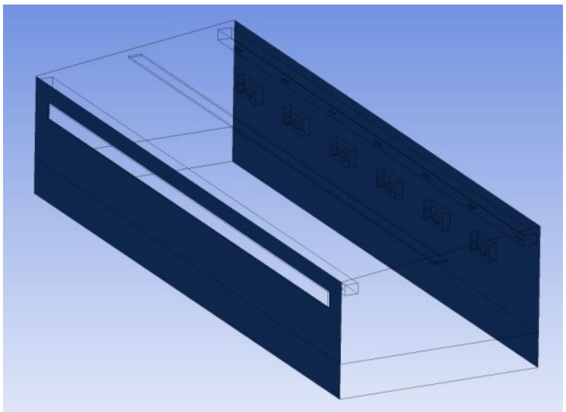


Figure 7. Border conditions for walls

For walls set thickness and heat conductivity, the outer heat-transfer coefficien, the outdoor temperature.

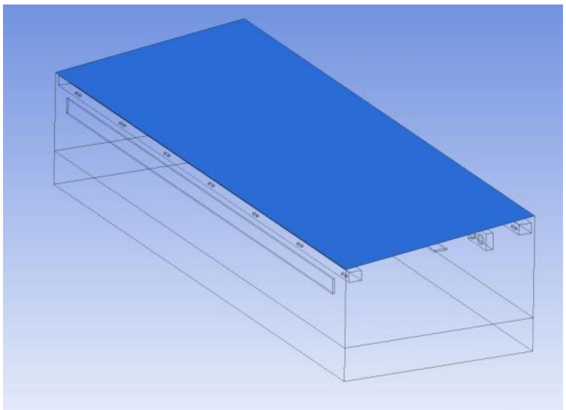


Figure 8. Border conditions for roof

For roof set thickness and heat conductivity, the outer heat-transfer coefficien, the outdoor temperature.

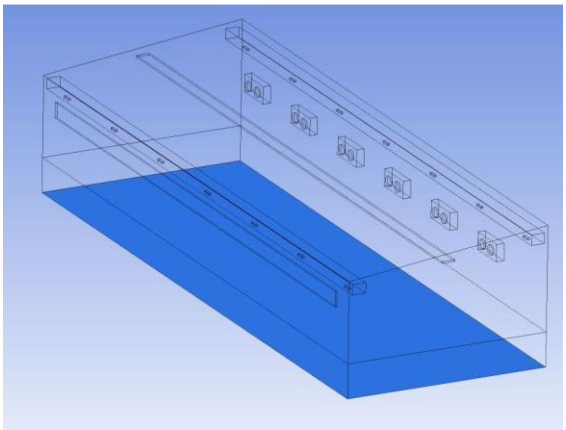


Figure 9. Border conditions for snow surface

For snow surface set constant temperature -5 C.

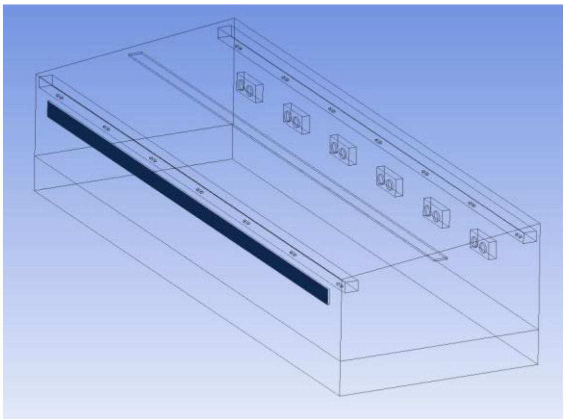


Figure 10. Border conditions for windows

For windows set reduced heat transfer resistance, the outer heat-transfer coefficient, the outdoor temperature.

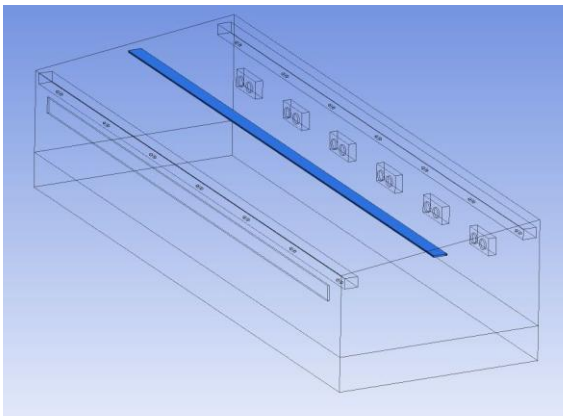


Figure 11. Border conditions for lighting

For lighting set designed heat generation.

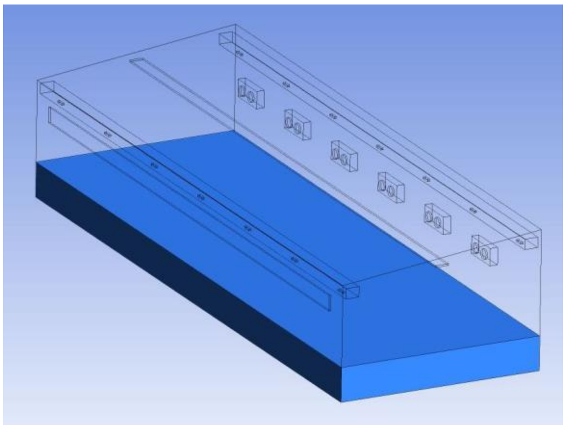


Figure 12. Border conditions for working area

For working area set designed heat generation from athletes.

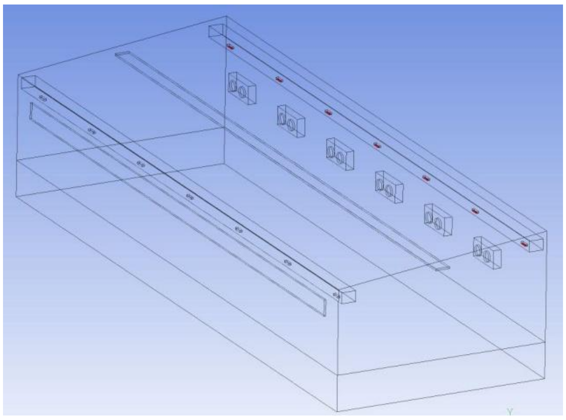


Figure 13. Border conditions for supply grills

For supply grills set designed air discharge and supply air temperature.

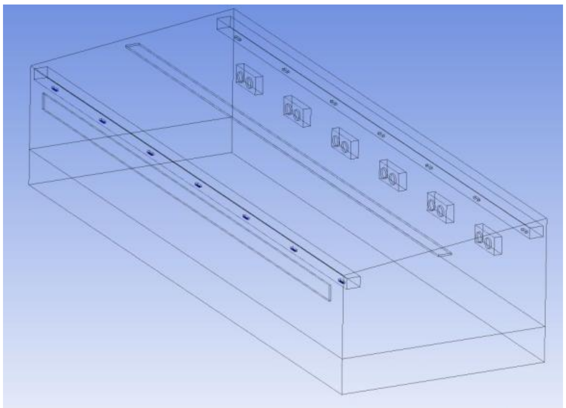


Figure 14. Border conditions for exhaust grills

For exhaust grills set designed air discharge and supply air temperature.

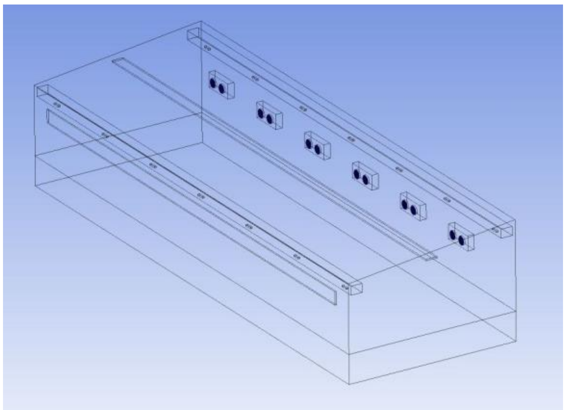


Figure 15. Border conditions for air coolers inflow (cold period)

For air coolers (cold period) set air discharge and temperature.

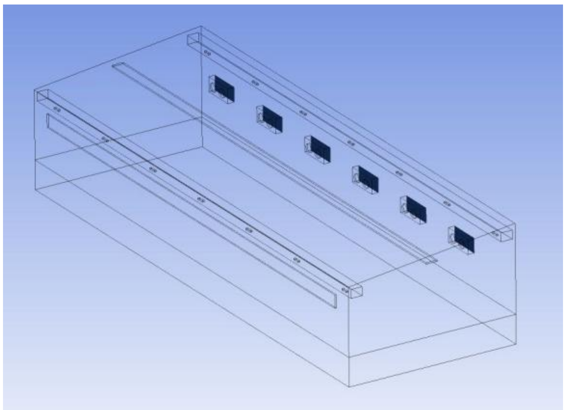


Figure 16. Border conditions for air coolers exhaust (warm period)

For air coolers (warm period) set air discharge.

The model is divided into knots Figure 17. Number of knots: 760 357 units.

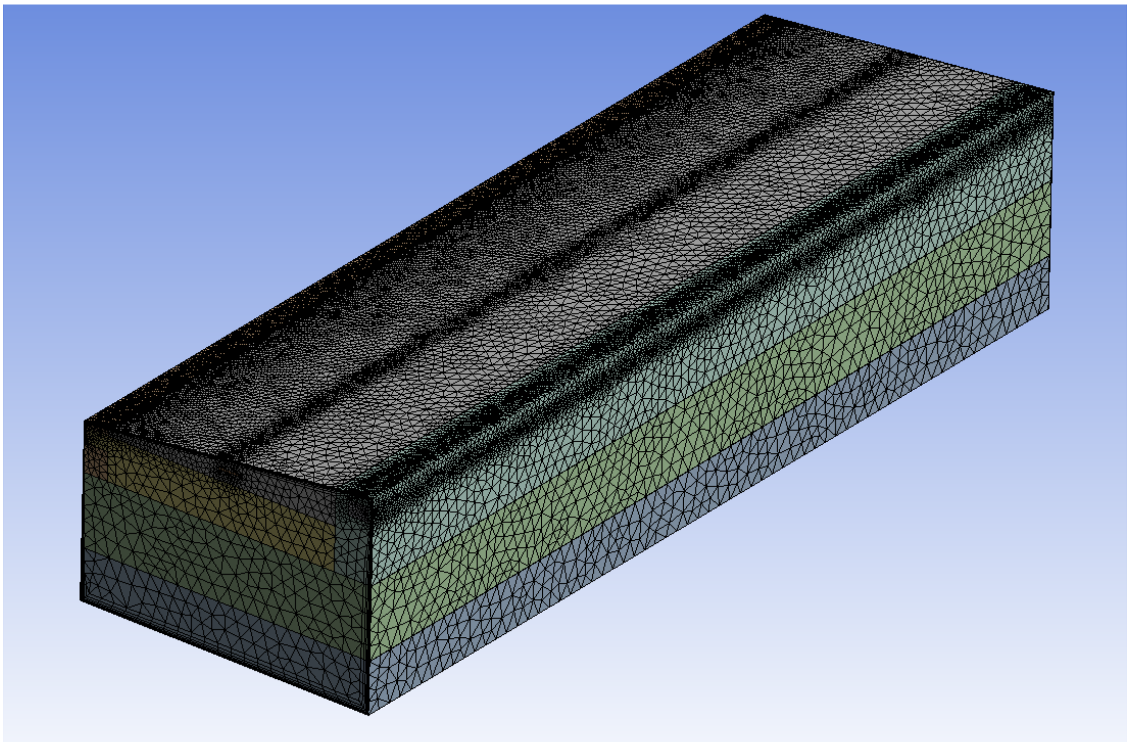


Figure 17. Design model

In the working area should be supported constant parameters of air:

- air temperature -5°C,

- air speed < 0.5 m/s.

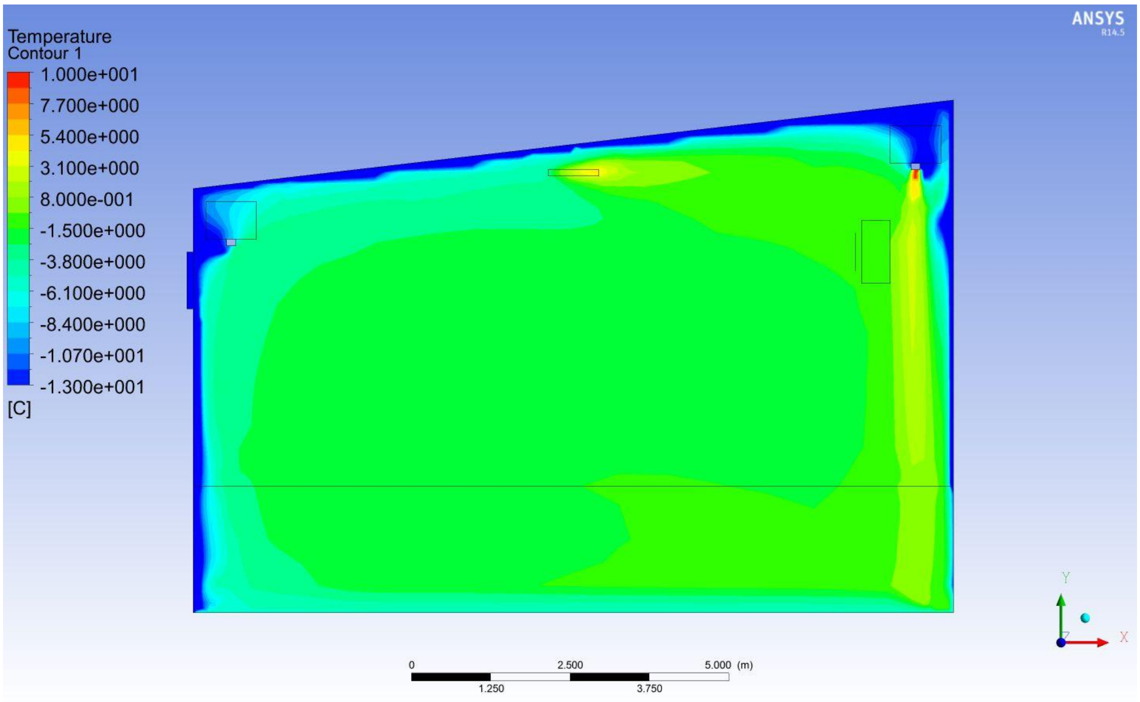


Figure 18. The first calculation - diagram of temperature (cold period)

Figure 18 shows a diagram of the temperature in the cold period, taking the calculated inflow temperature +10°C, the average temperature -1.6°C. That did not comply the required parameters.

The total heat loss by the Ansys program -17246 W, by calculation -11319 W. This is due to more accurate calculation of the Ansys program of the heat transfer coefficient of the inner surface of the enclosing structure α_{in}, in the shown before calculation α_{in} taken from table 6* [8] (accepted with reserve).

Figure 19 shows a diagram of temperature (cold period), after correction the supply air temperature became +7°C. Average temperature -5,0°C. Total heat loss -14642 W. Figure 20 shows air speed diagram. The required air parameters were complied, accepted the updated value of supply air +7°C.

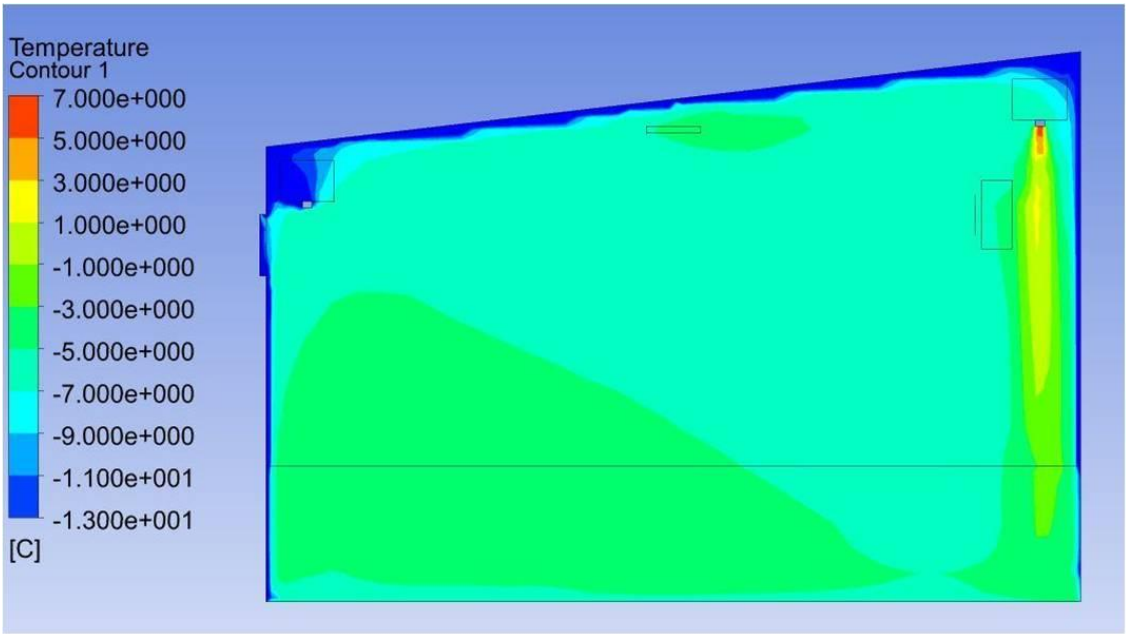


Figure 19. The second calculation - diagram of temperature (cold period)

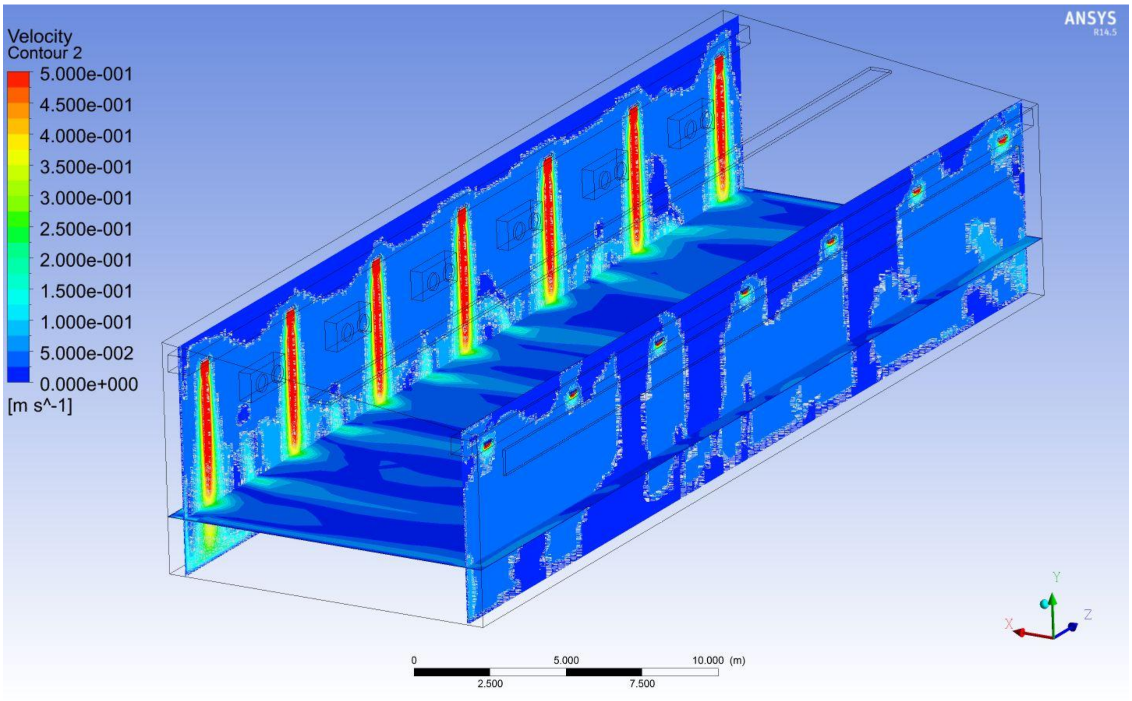


Figure 20. Air speed diagram (cold period)

Diagrams of speed and temperature in warm period were shown in figures 21 and 22. The average speed in the working area of < 0.5 m/s, the average temperature -5°C. The required air parameters are complied.

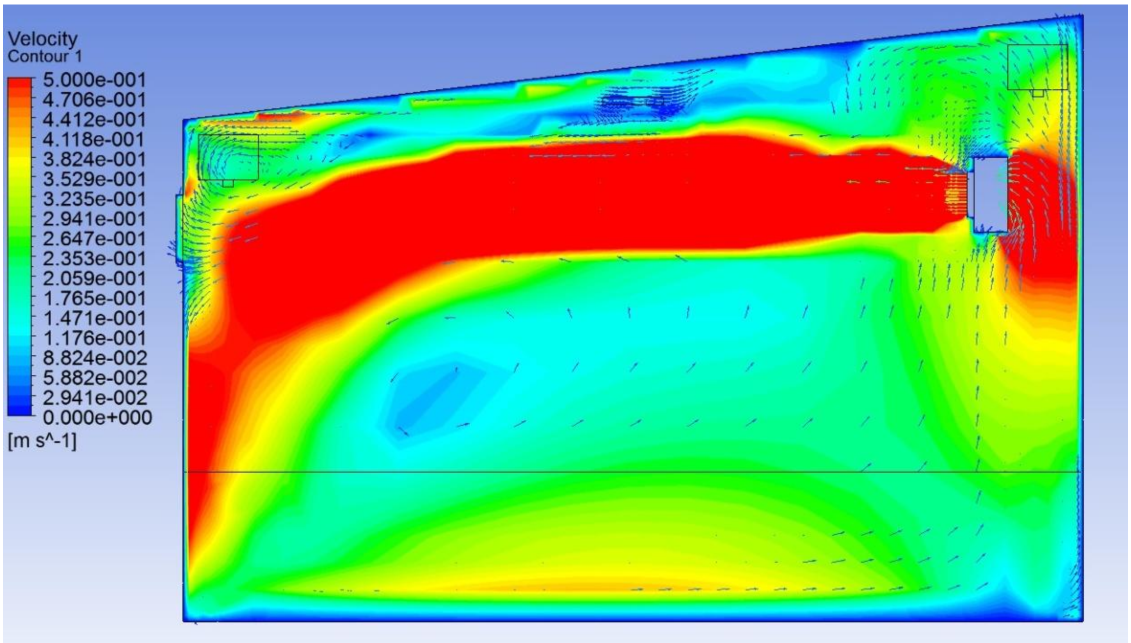


Figure 21. Air speed diagram (warm period)

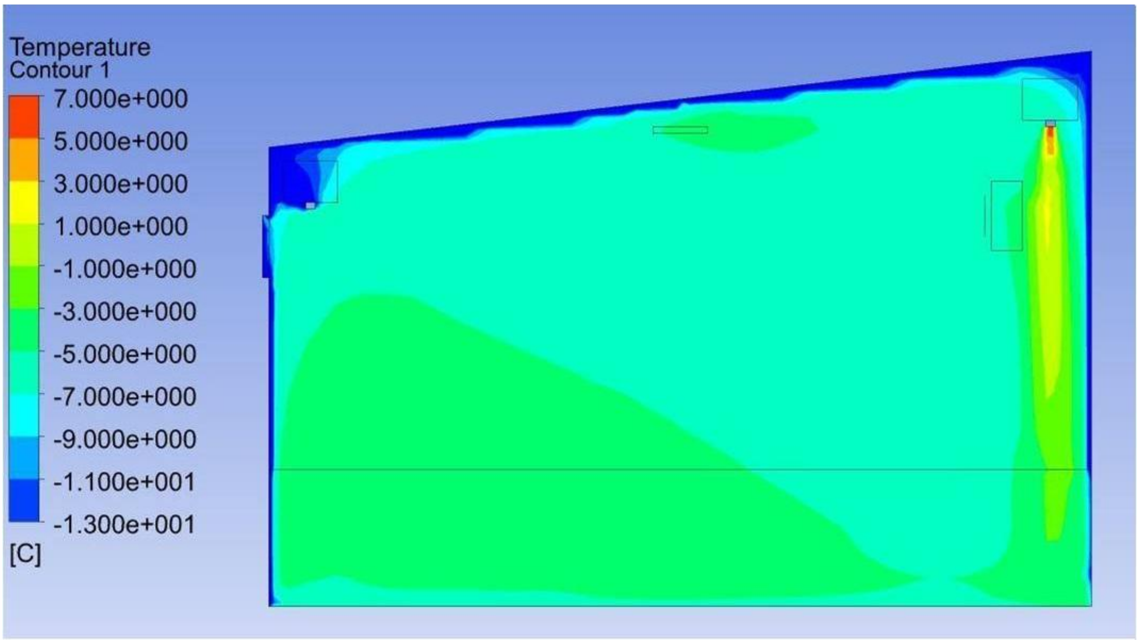


Figure 22. Diagram of temperature (warm period)

7 CONCLUSION

The ventilation and air conditioning system play an important role in the maintenance of normalized parameters of the microclimate in premises. Health and general state of people depend on parameters and conditions of the microclimate in the premise. The use of ventilation in tunnels due to the need to reduce to the allowable concentration of harmful gases, eliminate smoke and dust, creating the normal temperature rate.

The air exchange determines the quality of the microclimate and air environment. One of the biggest challenges is determining the required value of the air exchange for the premises. Sanitary-hygienic and energy efficiency of ventilation systems, as experience shows, is largely dependent on the rational organization of the air exchange and, specifically from the correct definition of the supply air flow and its distribution in the premises. Because of unsuccessful organization of the air exchange in the promise and because of wrong choice and calculation of air distribution, specified parameters of the air environment in the working area can’t be provide. Therefore, researches aimed at improving schemes of the organization of ventilation and methods of calculation of air exchange in buildings are relevant.

Currently, there are no methods for calculating ventilation in ski tunnels and also no recommendations for the optimal air distribution in the ski tunnel. The issue of establishing methods for calculating ventilation of ski tunnels is topical. Because existing methods for calculating ventilation in public buildings do not take into account all details for the correct organization of air distribution for this type of structures.

During writing the thesis thermotechnical calculation of the walling, calculation of ventilation system and air conditioning system for all sky tunnel and for selected section of the ski tunnel, and numerical simulation of the airflow on the section of the track for calculation temperature and velocity fields were made.

Within numerical simulation the following remarks were detected. Thermal and technical characteristics of walling need to be improved. Taking thermal resistance close to normalized value [7], when the available area nearby 20000 m^2, is unacceptable. Existing counterparts have heat transfer resistance over than the design value more than twice. The heat transfer coefficient of the inner surface of the walling taken by [7] equals to 8.7 W/m^2·s, and in the cold period has overestimated value, that during the design leads to installation of equipment with excessive heat consumption. The actual value is 2.5-3.5 W/m^2·s.

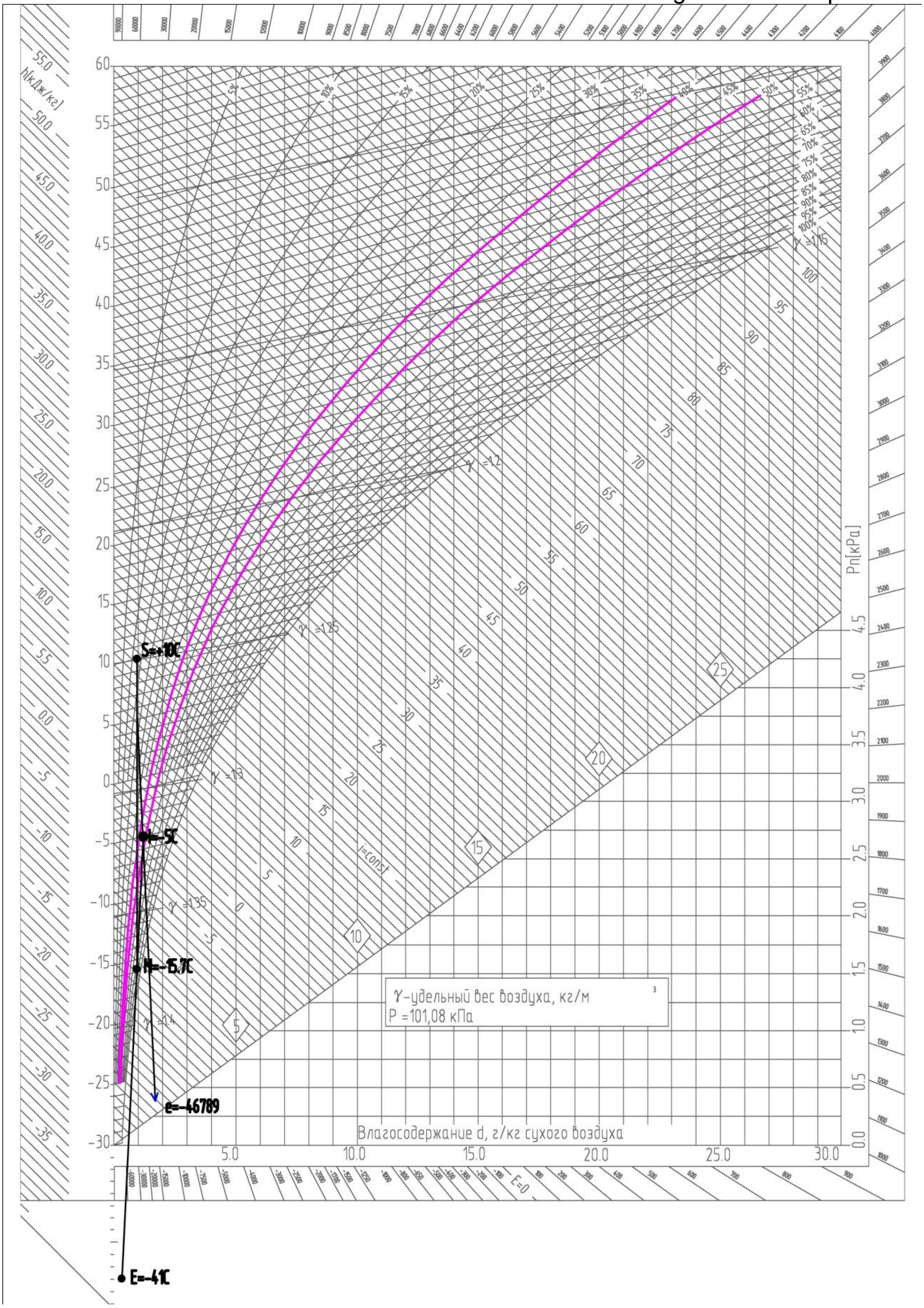
As the result of the thesis the air exchange on the section of the ski tunnel was developed. Presented plan of ventilation allows providing required parameters of microclimate. The received results (air discharge and supply air temperature, the parameters of the coolers) can be applied as reference material for designing and selecting equipment.

8 REFERENCES

1 TU 5284-001-74932819-2006 “Three-ply metal panels with mineral wool insulation boards”
2 GOST 31173-2003 “Steel door unit”
3 GOST 6629-88 “Wooden interior doors for residential and public”
4 GOST 21519-2003 “Aluminum window units”
5 SP 23-101-2004 “The design of thermal protection of buildings”
6 SNiP 23-01-99* “Construction climatology”
7 SNiP 23-02-2003 “Thermal protection of buildings”
8 SNiP II-3-79* “Construction thermotechnics”
9 Ananev V. A., Balueva L. N. 2003. Systems of ventilation and conditioning. Theory and practice. M euroklimat pp. 416.
10 Manual 2.91 to SNiP 2.04.05-91 “Calculation solar radiation heat to the premises”
11 VSN-1-73 “Standards of electric lighting of sports facilities”
12 SNiP 2.08.01-89 “Residential buildings”
13 SNiP 2.04.05-91* “Heating, ventilation and air conditioning”
14 SNiP 2.01.07-85 “Loads and actions”
15 SNiP 2.04.05-86 “Heating, ventilation and air conditioning”
16 SNiP 2.01.01-82 “Building climatology and geophysics”
17 SP 31-112-2004 “Sports halls”

18 SNiP 41-01-2003 “Heating, ventilation and air conditioning”
19 SP60.13330.2012 “Heating, ventilation and air conditioning”
20 Sotnikova O. A., Kuznetsov I. S., Gusev Y. L. 2007. Modeling of three-dimensional stationary distribution of air flows in rooms // Journal “Vestnik” of Voronezh technical University. № 6. pp.121-123.
21 Babakin B. S., Belozerov A. G. 2008. Mathematical modeling of the refrigerating food storage // Collection of scientific works. (Problems of refrigeration technology improvement). pp.77-82.

APPENDIX 1 Mollier diagram for cold period



APPENDIX 2 Mollier diagram for warm period