International Ecoenergy Academy

Authors: Aliyev Fagan, Aliyev Farhad
Editor: Nikrouz Forouzandeh Ghojehbeiglou

MICROCLIMATE OF CONSTRUCTION COMPLEX

BAKU-2017

PREPERED BY:
Fagan Aliyev, Farhad Aliyev
Nikrouz Forouzandeh Ghojehbeiglou

MICROCLIMATE OF CONSTRUCTION COMPLEX

DESIGN:
Ilham Aliyev

BAKU-2017

CONTENTS

INTRODUCTION

Construction complex is the largest consumer of electricity and heat energy. More extensive plot of land is required for construction complex in comparison with other civil buildings. All of these oblige the designers to approach the modern designing of constructions with special responsibility.

The task of normative microclimate establishment for complex facilities makes high requirements to the theory and calculation method that can be achieved through the application of modern computer and control technologies. The calculation methods should be based on the theoretical and experimental researches taking into account the interaction of processes in the complex: the system of microclimate conditioning – indoor environment – walling – outside climate.

At the present time, there are a number of publications concerning the functional, physical-technical, constructive and economic bases of the construction complexes' designing. However, in essence, the present book is the first publication in the domestic literature where an attempt was made to state a complex approach to the designing of engineering facilities and microclimate provision systems of construction complexes while considering them as an integrated energy system. The methods of physical and mathematical modeling of the microclimate of buildings, facilities and rooms were the basis of the designing methodology. Significant attention was paid to the substantiation of effective ways of reducing the energy consumed for the heating and cooling of buildings based on the application of modern computerized control systems and renewable energy technologies.

1. GENERAL EQUATION SYSTEM OF THE MICROCLIMATE OF THE CONSTRUCTION TERRITORY

The main task in the planning of the construction complex structure con sists in the improvement of microclimate of the territory. It can be solved through the establishment of an optimal building version, which will provide little changeability of the climatic factors in the area of the construction complex. The relevant architectural-planning decision will be the original damper of the changes in the climatic conditions and their converters: either to let decrease the "peak" climatic load in the areas of mass and continuous presence of people or to remove unfavorable conditions to the areas of the construction territory where the presence of people occurs episodically.

It is necessary to use modern calculation methods based on detailed mathematical description of the phenomenon and the methods of qualitative modeling of environmental factors including all complexes in searching for optimal design options.

The radiation, temperature and wind regimes of the territory are the main microclimate factors that determine the bulk planning structure of the cons truction complex. The radiation and temperature conditions assessment envisages the analysis of the solar radiation (duration and magnitude of the incomes to different parts of the building surface), analysis of the daily temperature changes in air and surfaces, as well as the wind regime. Assessment of the latter is implemented on the basis of the data on reiteration of the wind direction, possibility of incessant continuation of the wind speed of different gradation. It is expedient to introduce the microclimate assessment results in the form of mapped scheme, which reflects the changes of individual mic roclimate factors in the building territory (the maps of the wind and radiation regimes). These maps are used for the substantiation of the planning (geometric) restrictions, functional zoning of the building area and defining of the measures on the improvement of microclimate and sanitary – hygienic conditions in the constructed territory.

The efficiency of application of different constructional and architectural – planning measures for purposefully transforming the climate of the construc ted territory is determined on the basis of the building's microclimate formation features, as well as the level of the forecasting methods development for different parameters and microclimate of the building as a whole. Both the appropriateness of microclimate formation and the complex of the tasks asso ciated with its research may be understood better through considering the general system of the building microclimate equation.

The microclimate of the constructed territory (wind, temperature and radiation regime) is described by a complex equation system. Its solution seems impossible in general form. However, it is useful in the following practical cases:

- During the analysis of the main appropriateness of the wind, temperature and radiation regime of the building and their interconnection;
- During selection of simpler calculation modules allowing sometimes and analytical decisions;
- During substantiation of physical modeling of the building regimes.

The equation system describing the wind (aerodynamic), temperature and radiation regimes of the building includes:

Navier – Stokes equation of motion for viscous non-condensable fluid and the equation of continuity (aerodynamic regime):

$$\frac{\partial V_x}{\partial T} + V_x\frac{\partial V_x}{\partial x} + V_y\frac{\partial V_x}{\partial y} + V_Z\frac{\partial V_x}{\partial z} = -\frac{1\partial p}{\rho\partial x} + \upsilon\Delta V_X \tag{1.1}$$

$$\frac{\partial V_y}{\partial T} + V_x\frac{\partial V_y}{\partial x} + V_y\frac{\partial V_y}{\partial y} + V_Z\frac{\partial V_y}{\partial z} = -\frac{1\partial p}{\rho\partial y} + \upsilon\Delta V_y \tag{1.2}$$

$$\frac{\partial V_z}{\partial T} + V_x\frac{\partial V_z}{\partial x} + V_y\frac{\partial V_z}{\partial y} + V_Z\frac{\partial V_z}{\partial z} = g\beta(t - t_\infty) - \frac{1}{\rho}\frac{\partial p}{\partial z} + \upsilon\Delta V_z \tag{1.3}$$

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} + \frac{\partial V_z}{\partial z} = 0 \tag{1.4}$$

The equation of energy (temperature regime):

$$\frac{\partial t}{\partial T} + V_x\frac{\partial t}{\partial x} + V_y\frac{\partial t}{\partial y} + V_Z\frac{\partial t}{\partial z} = a\Delta t \tag{1.5}$$

The ratio describing the distribution of the solar radiation in the building (radiation regime):

$$I_s = I(h, A_c, S) \tag{1.6}$$

The system of equations (1.1) – (1.6) has boundary conditions:

$$V\,x \to \infty, y \to \infty, z \to \infty = V_\infty;\ V_{z=0} = 0;\ V_t = 0;$$

$$t\,x \to \infty, y \to \infty, z \to \infty = t_\infty\ ;\ -\lambda\frac{\partial t}{\partial z}(z = 0) = a(t - t_{z=0}) + \overline{\rho_e}I_e \tag{1.7}$$

$$-\lambda\frac{\partial t}{\partial h}(s) = a(t - t_s) + \overline{\rho_s}I_s$$

where τ – time; *x*, *y* and *z* – coordinates; t – air temperature; *h* – height of the sun; A_c-azimuth of the sun; V_x, V_y, V_z-components of the speed; p- pressure; 1 – density of the flow of the summary solar radiation; ρ – density of air; υ – coefficient of the air kinematic viscosity; β- coefficient of the volumetric extension; λ-coefficient of heat conduction; ρ_e and ρ_S-coefficient of absorption of the solar radiation in accordance with the surface of the earth and the barrier; α – coefficient of the heat conduction; Δ – Laplace operator.

The system of equations (1.1)-(1.6) includes six unknowns: three compo nents of speed, pressure, temperature and the density of the solar radiation flow on the surface. The arguments are: time, space coordinates, angular coordinates of the sun and the coordinates determining the position of the building elements.

In general, the system is transient. It may seem that inclusion of non-sta tionary members is excessive, as the boundary conditions don't depend on time. But, it is stipulated with the features of the wind regime. At it is known from the mechanics of liquid and gas, under enough great speed of the regime of flow around body is non-stationary: vortex like masses inhibited by the body liquid is broken away from the different parts of the surface creating hesitations in the flow with the frequency depending on the speed of the flow and its viscosity and also the sizes and forms of the body. The similar pheno mena are observed during wind flow with great speed around the building.

From all equations of the system (1.1) - (1.6) the equation (1.6) may be settled independently, i.e., the calculation of the radiation regime may be implemented separately. In the general case, all other unknown functions depend on the radiation. The formal dependent of the temperature on the radiation is described with the boundary conditions (1.7). The air speed depends on the temperature (1.3) and consequently, on radiation too.

The analysis of the equations of air movement shows that the first member in the right part of the equation (1.3) characterizing the lifting powers functioning in the air and stipulated by differences of the density of heated and cooled mass of air within the building is smaller in comparison with the mem bers describing the convection and as a rule, it can be disregarded. Then the equations (1.1)-(1.4) characterizing the aerodynamic regime of the building can be settled separately and the possibility of isolated research of the wind regime of the building is concluded by it not by theoretical, but also experimental method too.

The consideration of the equation (1.5) and boundary conditions shows that it is necessary to know the features both of the wind regime (speed components V_x, V_y, V_z) and the radiation regime in order to fulfill the analysis of the temperature regime. In this case, particularly the difficulty of modeling of the heat regime has been revealed, as this character is complex.

The boundary conditions of the system of equations (1.1) - (1.6) are determined by the definition of the sizes reflecting the conditions of the surface of the earth and on the external surface reflecting the construction. Particularly, the temperature of these surfaces is unknown and depends on some factors: the temperature of the premise, barrier constructions and so on. Hence, this temperature may be determined according to the results of the approximate calculations and in – situ measurements.

It has already been stated that solution of the system of equation of the microclimate of the constructed territory is impossible, but the analysis of its structure allows to state the most general algorithm of research of the microclimate of the constructed territory using both different calculation and experimental methods. Generally, it seems as following:

- Research of the wind regime of the building (mainly via experimental methods of modeling);
- Research of the radiation regime of the building (mainly via calculation methods);
- Research of the temperature regime using the results of the research of the wind and radiation regimes of the building (calculating and experimental methods);
- Complex assessment of the microclimate of the built-up territory (mainly calculating estimation on the basis of the bioclimatic equation).

2. THE WIND (AERATION) REGIME OF THE CONSTRUCTION TERRITORY

The presence of buildings essentially modifies the wind regime of the territory. The wind changes its speed under their impact, and the zones protected against wind where the speed of air flow movement decreases in two -three times and the direction may be opposite to the basis are established. At low wind speeds, the local air flows arisen in the building because of uneven heating of the building's wall surface by the Sun, asphalted passages and so on may have significant influence on the wind regime.

The area of building where braking of flow occurs due to the vortex for mation in its built-up part spread to a distance about 6 height of the building and depends on its form and direction. But, the sphere of the building influence the air flow not ended outside the area and the braking of flow may be noti ceable within the distance reaching to 15 height and more. The wind regime is significantly complicated in view of mutual effect of neighboring buildings on the air flow when the number of buildings increases: the areas of "wind shadow" and "through wind" appear. The speed specter becomes so compli cated in the building that the analysis of the wind regime near the separate buildings is impossible. In this case, it is necessary to implement the research on the wind regime of the building as a whole, on the basis of which it is expedient to develop the map of the wind regime of the territory that allows to solve the following practically important tasks:

- *to choose an optimal version of the building location in the territory;*
- *to outline the town planning measures on the regulation of the building aeration processes;*
- *To find out optimal placing of the landscaping elements (grounds, roads and so on);*
- *to calculate the wind influence on the building and loss of heat energy due to the infiltration of the external air through the enclosing constructions;*
- *to determine the aeration regimes of the buildings and their separate elements (premises, ventilated coverings and so on).*

According to the estimations of F. L. Serebrovsky [1], the efficiency of regulation of the wind regime of the building territory due to architectural – planning means is very high. The wind speed may be decreased to 85% in comparison with the wind speed in undeveloped area, and it can be increased nearly twice when it is necessary. Protection of buildings against the direct influence of wind decreases the heat loss for 10 – 15%. All of these stipulate the necessity of research on the wind regime of the future buildings.

2.1. Theoretical positions of physical modeling of the wind regime

The main method of learning the interaction between the wind and the apartment block is modeling based on the aerodynamic similarity. Getting analytical solution in view of extremely difficult geometry of the objects, as well as the equation systems describing the process of formation of the wind regime is possible only in some simple cases. Because of the same reasons, the numerical methods of solution of the equations by application of calculations tools are more effective than the analytical methods.

Research of the wind regime under in-situ conditions for the purpose of obtaining useful results is accompanied by many difficulties for designing the building, for example with impossibility to recreate necessary turndown of the parameters of incoming flow (sizes and directions of wind speed, turbulence intensiveness and so on). Besides, forecasting the wind regime in the building is especially valuable just in the designing process, as zoning of the territory is necessary. The single way out is modeling of the process in the laboratory conditions.

The theoretical basis of the experiments on modeling is the similarity theory according to which two physical phenomena are considered alike if the differential equations describing their identical, initial and boundary con ditions where they flow are alike. The similarity criterion representing dimen sionless complexes of physical values characterizing the given phenomenon may be determined from these equations.

As it is stated, the analysis of the wind regime of the building may be implemented separately from the temperature and radiation regime under known assumptions. The equation system describing air movement in the building and the boundary conditions are described as following:

$$\frac{\partial V_x}{\partial T} + V_x\frac{\partial V_x}{\partial x} + V_y\frac{\partial V_x}{\partial y} + V_Z\frac{\partial V_x}{\partial z} = -\frac{1\partial p}{\rho\partial x} + v\Delta V_X$$

$$\frac{\partial V_y}{\partial T} + V_x\frac{\partial V_y}{\partial x} + V_y\frac{\partial V_y}{\partial y} + V_Z\frac{\partial V_y}{\partial z} = -\frac{1\partial p}{\rho\partial y} + v\Delta V_y \tag{2.1}$$

$$\frac{\partial V_z}{\partial T} + V_x\frac{\partial V_z}{\partial x} + V_y\frac{\partial V_z}{\partial y} + V_Z\frac{\partial V_z}{\partial z} = g\beta(t - t_\infty) - \frac{1}{\rho}\frac{\partial p}{\partial z} + v\Delta V_z$$

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} + \frac{\partial V_z}{\partial z} = 0$$

$$\mathrm{V\ x} \to \infty, y \to \infty, z \to \infty = V_s;\ V_{z=0} = 0;\ V_s = 0$$

The system (2.1) is brought to the dimensionless form in order to deter mine the similarity criterion. It is comfortable to adopt permanent values and physical constants included in the system equations as the scale of size values. The scale of the linear sizes L, m (any characteristic size of the building, for example height or length); the speed scale V∞, m\s (speed of undistributed scale), temperature scale (t_0-t∞), C°(tω-air temperature outside the building, t_0 – some characteristic temperature, for example temperature of underlying surface or the temperature of the surface of the walls of the building), time scale L_2\v, c; pressure scale pV ∞, H\m^2.

Let's introduce the designation of dimensionless variables:

$$T' = \frac{T}{L^2}v,\ x' = \frac{x}{L}, y' = \frac{y}{L}, z' = \frac{z}{L}$$

$$V_x' = \frac{V_x}{V_\infty}, V_y' = \frac{V_y}{V_\infty}, V_z' = \frac{V_z}{V_\infty}, p' = \frac{p}{\rho V_\infty^2}, \theta = \frac{t-t_\infty}{t_0-t_\infty} \qquad (2.2)$$

After altering the variables in the system (2.1) according to the synesthesia (2.2) and abridgement of both parts of the equation on V∞ \L^2, system (2.1), the following is obtained:

$$\frac{\partial V_x'}{\partial T'} + \frac{V_\infty L}{v}\left(V_x'\frac{\partial V_x'}{\partial x'} + V_y'\frac{\partial V_x'}{\partial y'} + V_z'\frac{\partial V_x'}{\partial z'}\right) = -\frac{V_\infty L}{v}\frac{\partial p'}{\partial x'} + \Delta V_x'$$

$$\frac{\partial V_y'}{\partial T'} + \frac{V_\infty L}{v}\left(V_x'\frac{\partial V_y'}{\partial x'} + V_y'\frac{\partial V_y'}{\partial y'} + V_z'\frac{\partial V_y'}{\partial z'}\right) = -\frac{V_\infty L}{v}\frac{\partial p'}{\partial x'} + \Delta V_y' \qquad (2.3)$$

$$\frac{\partial V_z'}{\partial T'} + \frac{V_\infty L}{v}\left(V_x'\frac{\partial V_z'}{\partial x'} + V_y'\frac{\partial V_z'}{\partial y'} + V_z'\frac{\partial V_z'}{\partial z'}\right) = \frac{g\beta(t-t_\infty)L^3}{v^2}\frac{v}{V_\infty L}\theta - \frac{V_\infty L}{v}\frac{\partial p'}{\partial z'} + \Delta V_z'$$

$$\frac{\partial V_x'}{\partial x'} + \frac{\partial V_y'}{\partial y'} + \frac{\partial V_z'}{\partial z'} = 0$$

$$V'_{\substack{x'\to\infty \\ y'\to\infty \\ z'\to\infty}} = 1; V'_{z=0} = 0;\ V_s' = 0$$

Dimensionless complexes included in the system (2.3) are some required similarity criterion:

$Re = \frac{V_\infty L}{v}$ Reynolds criterion

$Gr = \frac{g\beta(t-t_\infty)L^3}{v^2}$ Grasgof criterion

Taking into account these signs, let's rewrite the main equations of the system:

$$\frac{\partial V_x'}{\partial T'} + Re\left(V_x'\frac{\partial V_x'}{\partial x'} + V_y'\frac{\partial V_x'}{\partial y'} + V_z'\frac{\partial V_x'}{\partial z'}\right) = -Re\frac{\partial p'}{\partial x'} + \Delta V_x'$$

$$\frac{\partial V_y'}{\partial T'} + Re\left(V_x'\frac{\partial V_y'}{\partial x'} + V_y'\frac{\partial V_y'}{\partial y'} + V_z'\frac{\partial V_y'}{\partial z'}\right) = -Re\frac{\partial p'}{\partial x'} + \Delta V_y' \qquad (2.4)$$

$$\frac{\partial V_z'}{\partial T'} + Re\left(V_x'\frac{\partial V_z'}{\partial x'} + V_y'\frac{\partial V_z'}{\partial y'} + V_z'\frac{\partial V_z'}{\partial z'}\right) = \frac{Gr}{Re}\theta - Re\frac{\partial p'}{\partial z'} + \Delta V_z'$$

Thereby, if in two fields of speed (for example, the field of speed of the building and models) the criteria of Reynolds and Grasgof are identical, in the dimensionless variables, they are described by the same system of equation and designs their similarity, i.e., homological moments of time [equally, dimensionless time determined according to (2.2)], the value of the dimensionless speeds coincides in the homological points of the space (geometrically similar points). If one field of speed (model) is known, then according to (2.2) the dimensionless valuables of all similar fields may be determined and the characteristic of the speed field of the building is calculated according to the same correlation (2.2) using the scale of the in-situ field.

The physical meaning of the Grasgof criterion is the ratio of the bearing capacity stipulated by the variety of density of heating and cooling particles of weather to the viscosity power. Streamline of air flow of the building by this bearing capacity may be neglected in comparison with inert power which is described by other members in the left part of the equation system for most of practically necessary cases (2.4). It has already been noted during conside ration of the general equation system (1.1). Therefore, observing equality of Grasgof criterion in- situ and model is not obligatory.

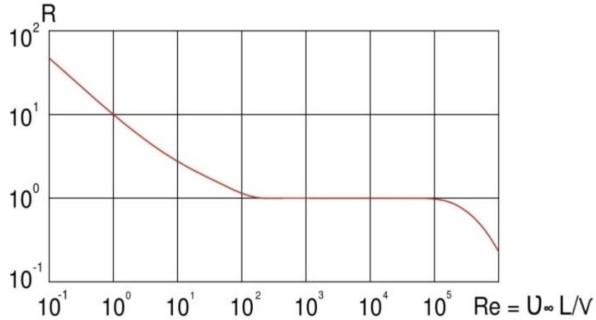
After excluding the Grasgof criterion, the Reynolds criterion becomes determinative for the modeling of the building wind regime. The physical meaning of the Reynolds criterion is the ratio of the inertial forces to the forces of friction, i.e., it determines the dependence between the linear sizes of the streamlined body, the flow speed and the kinematic viscosity of the medium. The sizes of the model, as a rule are 100…. 500 times less than the sizes of real buildings during modeling of the building. As the possibility of changing the viscosity of the medium is limited during modeling, proportional decrease of the sizes of increase of speed of the incident flow is required for maintaining the model and nature of the Reynolds value. The latter is not possible, as the flow speed required for the model exceeds the voice speed, the weather stops behaving as non-condensable fluid and the initial equations become invalid under these conditions.

The way out from this position can be found by analyzing the features of the streamline of rectangular, poor streamlined bodies which the models of the building are. If to place the body in the air flow and to change the speed of this flow, it turns out that neither the kinematics of streamline of this body, nor the dynamics of their interconnection are not practically changeable in the wide range of speed change [2]. The known fact of independence of the coefficient of body resistance R streamlined in wide velocity range (Reynolds number) on the Reynolds number (10^3 – 10^5 Re) is its indirect confirmation (picture 2.1).

The self – similarity of the speed fields against Reynolds criterion may be physically explained by the fact that the power of viscous friction is commensurate with the inertial power only within the framework of the boundary layer, i.e., in indirect closeness from the walls of the body. We have interests in the speed field outside the boundary layer, where the fluid with enough level of exactness may be considered as ideal.

In case, if the Reynolds numbers are more than 10^6 (see picture 2.1) the self – similarity principle shall be applied carefully.

Pic. 2.1 *Dependence of the coefficient of resistance of the streamlined body from Reynolds number*



Under these Re values turbulent phenomenon takes the whole flow, the recorded non-stationarity of the flow is observed behind the body and its turbulent viscosity becomes essential. F.L.Serebrovky introduced the following correlation for the self- similarity of the speed field [1]:

$$V_\infty^M / V_\infty^H = (L_M / L_H)^{1/3} \quad (2.5)$$

where, $V\infty^M$ and $V\infty^H$ are the speeds of undistributed flow in the model and building, and $L_{M,}$ L_H are the scales of the linear sizes in the model and building, respectively.

In this case, he used the equation of movement taking into account the experimental dependences for turbulent viscosity.

However, the streamline regime of the body may be exactly modeled only maintaining the geometric similarity for great number of scientific and technical tasks, and particularly for the tasks associated with the wind regime of the building. Implementing the equality of Reynolds criteria in the model is compulsory.

Thus, the method used in the wind regime modeling is called the approximate modeling, to which M.V. Kirpichev and M. A. Mikheev gives the following definition: "The approximate modeling is the mixed theoretical-experimental method, which establishes the requirements raised by the theory for getting total similarity in the model and reveals which requirement can't be implemented without noticeable distortion of similarity through experimental comparison of the model with the example". The method of approximate modeling provides for creation of the model which is simpler than the nature. Therefore, it is necessary to develop the substantiated methods of the approximate modeling taking into account concrete features of the studied phenomenon and the volume of available information about it, and the character of the task set for the model of the work environment, as well as technical means for carrying out experiments. Only those models for which the value of possible mistake is determined can be accepted as the methods of approximate modeling. It shall also limit the field of application of the mentioned methods and determine the limits where the results of experiments will not exceed the established error.

2.2. The method of research of the building wind regime

As it is shown above, the principal method of study of the wind (aerody namic) regime of building is the method of physical modeling where the aerodynamic pipes, flat and voluminous hydraulic chutes are used as the experimental equipment. The main advantage of the latter is the possibility of visual observation of the character of aerodynamic flow around the building.

The scheme of a flat hydraulic chute of the Khanjonkov system is given in picture 2.2. The water is given to the hydraulic chute through the nozzle system directly from the water supply network. Passing through the side channels the water enters to the damping part having great depth and designed for discharging the turbulence occurring during outflow from the chute. Later, the fluid passes to the working part of the hydro-chute after which some part of the liquid will enter again to the side channel due to the ejection effect.

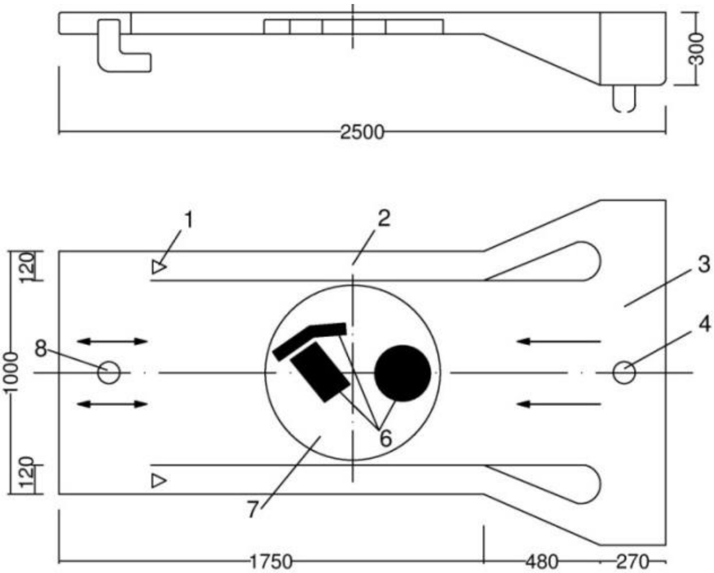
Surplus of the fluid enters to the sewerage network through the nozzle. The bleed hole is designed for emptying the chute after finishing of the experiment. The split socket in the nozzle lets change the height of the layer of water in the chute. The model of the building is determined on the rotatable basis that allows changing the position of the building relatively to the direction of the incident flow of fluid in experimental process, and consequently easily modeling different wind directions or different positions of the building.

Photographs is taken from above,in this case the exposition shall be enough so that the trajectory of seen particles (aluminum powder and so on) floating on the surface of the fluid be fixed on the film in the form of strokes (they are received in the form of points in instant extract). The strokes nearer to the straight line may be considered the vectors of speeds in every point in the fixed scale. The size of the speed m\s is determined upon the following formula in some points:

$$\mathrm{V} = I_l M_F / t_{exp} \tag{2.6}$$

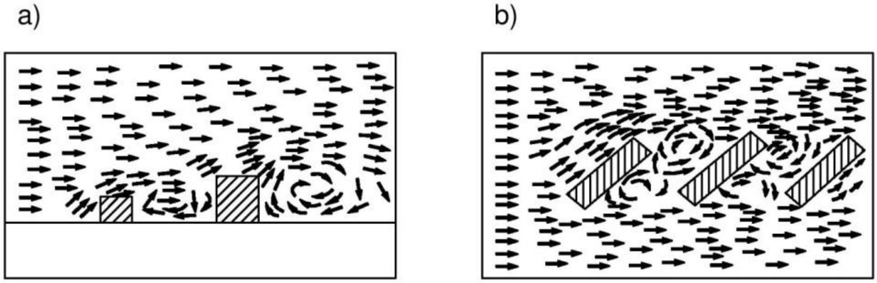
where l_l – the length of the stroke in some points of the film, mm, M_F- scale of the film relative to the model, m\mm; $t_{exp.}$ – exposition time of the film;

Pic. 2.2 The scheme of hydro-chute of the Khanjonkov system



1. Jet; 2. Side channel; 3. Damping part of the channel; 4. Bleed hole; 5. Working part of the hydro-chute; 6. Model of the building; 7. Rotatable basis for determination of the model; 8. Nozzle for moving off the surplus of the fluid.

Pic. 2.3 The streamline character of the building area



a – in the vertical profile; b – in the plan;

As the movement speed of the fluid may differ a lot in the different points of the model of the building, then it is recommended to duplicate the pictures in the different time of the exposition. According to the results of pictures and film scanning, it is expedient to build the schema of streamline of the buildings giving qualitative presentation about the wind regime of the building *(picture 2.3).*

The qualitative character of the wind regime gives the map of the zones with increased and decreased wind speed in the building. The velocity range in the building is broken into some gradations in the shares from the speed of the incident flow V∞ which each of them is relevant to certain mean value of speed. All of speed gradations appropriate to the graphical meaning and con ditional naming (table 2.1).

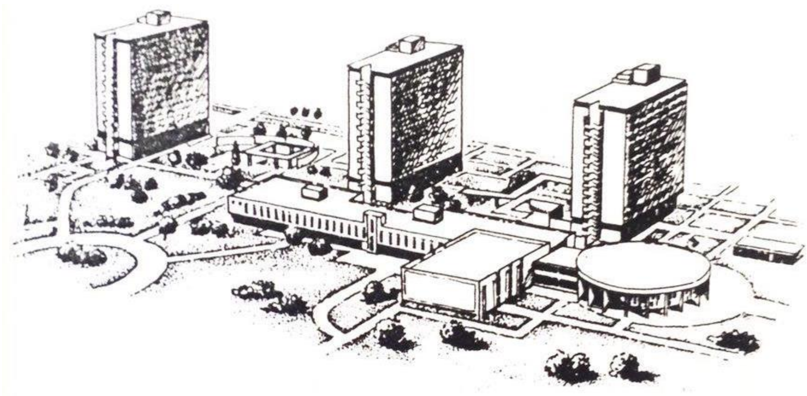
Table 2.1 Speed gradation in the building area

Gradation of high-speed fields in the building area (in fractions of V∞)	Characteristics of gradation of high-speed fields	Average speed	Designation
0 – 0,4	Very small	0,2	
0,4 – 0,8	Small	0,6	
0,8 – 1,2	Normal	1,0	
1,2 – 1,6	Big	1,4	
1,6 – 2,0	Very big	1,8	
2,0 – 2,4	Maximum	2,2	

The model of the building is shown in picture 2.4 and the distribution of the zones of different gradations of the wind speed corresponding to this building is shown in picture 2.5. As a rule, the analogical maps are drawn up for every direction of wind (N, NE, E, NE, S, SW, W, NW)

The maps of the zones of gradation of the wind speed in the building, as well as the information about the wind regime of the construction district (in the speed and repletion of wind for each of eight principal directions) serves as the initial material for determination of the integral characteristic of the wind regime of the building which in its turn is the criterion of estimation of the quality of the planning decision.

Pic. 2.4 The model of the construction complex



The system of the integral criteria of the building wind regime assessment includes: average speed of the wind in the building, the security coefficient and blowing of the territory for each direction, as well as the mean values of these parameters taking into account the repetition of wind for each direction [1].

The average wind speed for each direction in the building territory is determined according to the following formula:

$$V_N = \frac{1}{F}\sum_{m=1}^{M} F_m^n V_m^n = V_\infty^N \sum_{m=1}^{M} (F_m^N/F \cdot V_m^N/V_\infty^N)$$

$$V_{NE} = V_\infty^{NE} \sum_{m=1}^{M} (F_m^{NE}/F \cdot V_m^{NE}/V_\infty^{NE}) \qquad (2.7)$$

$$V_{NW} = V_\infty^{NW} \sum_{m=1}^{M} (F_m^{NW}/F \cdot V_m^{NW}/V_\infty^{NW})$$

where V_N,V_{NE}, …V_{NW} – the average values of wind speeds in the building territory for different wind directions, m\s; F – the area of the housing territory excluding the area of the building, m; F_m^N, F_m^{NE}, F_m^{NW}-areas taking third gradation of the speed for relevant wind direction, m; F_m^N \F, F_m^{NE} \F,…. F_m^{NW} \F - relative areas taking the third gradation of the speed determined on the maps of the zone of the wind speed gradation in the building; V_∞^N, V_∞^{NE} …

V_∞^{NW}-average wind speed outside the building territory for each wind direction, m\s; V_m^N, V_m^{NE} … V_m^{NW}- average speed of the third gradation of the speed for relevant wind direction, m\s; $V^N \backslash V_\infty^N$, $V_m^{NE} \backslash V_\infty^{NE}$ … $V_m^{NW} \backslash V_\infty^{NW}$- average relative velocities of the third gradation of speed for relevant wind direction determined on the map of the zone of the wind speed gradation in the building; M – number of speed gradation.

The average speed in the building area for all wind directions V (%) is determined by the following formula:

$$\overline{V} = (V_N P_N + V_{NE} P_{NE} + \cdots + V_{NW} P_{NW}) \Big/ 100 \tag{2.8}$$

where p_n, p_{ne}….. p_{nw} -are the repetition of wind for the relevant direction, %.

The coefficient of protectability of the territory (%) for each wind direction-the ratio of the area with low wind speed to the total area being free from construction is determined according to the following formula:

$$\varphi_{1,N} = \sum_{m=1}^{M_1} (F_m^N / F) \, 100$$
$$\varphi_{1,NE} = \sum_{m=1}^{M_1} (F_m^{NE} / F) \, 100 \tag{2.9}$$
$$\varphi_{1,NW} = \sum_{m=1}^{M_1} (F_m^{NW} / F) \, 100$$

where M_1 – the number of speed gradation corresponding to the low wind speed.

The average value of the coefficient of the territory's protectability (%) is determined according to the following formula:

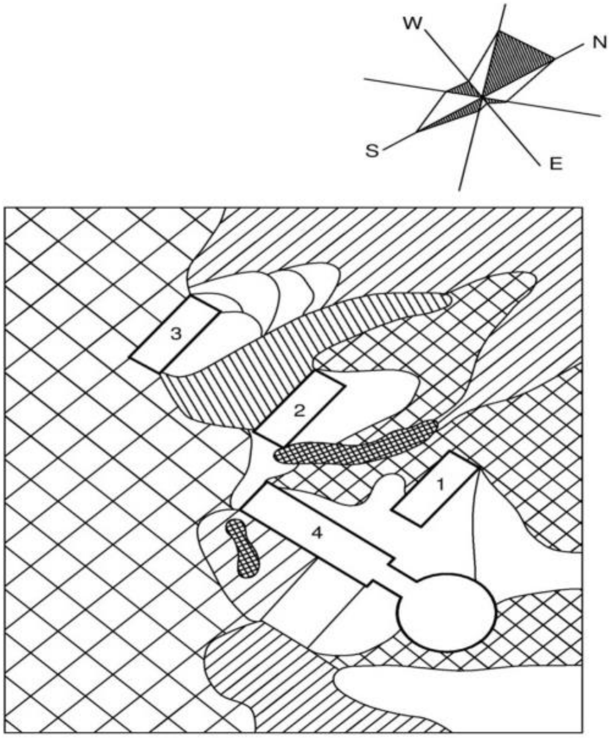
$$\overline{\varphi}_1 = (\varphi_{1,N} P_N + \varphi_{1,NE} P_{NE} + \cdots + \varphi_{1,NW} P_{NW}) / 100 \tag{2.10}$$

The blowing coefficient of the territory (%)-the ratio of the area of incre ased wind speed to the areas free from the construction is determined according to the following formula:

$$\varphi_{2,N} = \sum_{m=1}^{M_2} (F_m^N / F) \, 100$$
$$\varphi_{2,NE} = \sum_{m=1}^{M_2} (F_m^{NE} / F) \, 100 \tag{2.11}$$
$$\varphi_{2,NW} = \sum_{m=1}^{M_2} (F_m^{NW} / F) \, 100$$

where M_1 -the number of speed gradation corresponding to the increased wind speed.

Pic. 2.5 The map of distribution of the zones with decreased and increased wind speed in the building area (see Table 2.1)



1. building № 1; 2. building № 2; 3. building № 3; 4. household corps.

The average value of the blowing coefficient of the territory (%) is determined by the following formula:

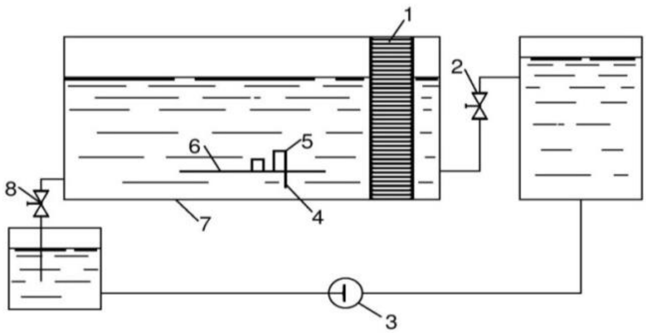
$$\overline{\varphi}_2 = (\varphi_{2,N}P_N + \varphi_{2,NE}P_{NE} + \cdots + \varphi_{2,NW}P_{NW})/100 \quad (2.12)$$

The maximum value corresponding to the low wind speed and the minimum value corresponding to the increased wind speed in the building territory are taken depending on the climatic conditions of the construction area and the designation of the building when φ1 and φ2 are determined.

The values of V, φ1 and φ2 are the criteria for the estimation of the planned design in accordance with the requirements made to the building. For example, the minimum V and φ2 values will be optimal for the regions with severe and cold winds and the maximum V and φ2 values will be optimal for the hot and low-windy regions.

Another type of hydrochutes applied during research of the buildings' wind regime is voluminous hydrochute (picture 2.6). The known limitation of the possibilities of research in the flat hydrochute is associated with the fact that two – dimensional model of the building wind regime is realized in it. Despite the fact that in the most cases the theoretical and experimental researches showed such kind of approach acceptable, but in some cases they prefer voluminous version of hydrochute, as the flow is tree-dimensional in the last model.

Pic. 2.6. Principal scheme of the voluminous hydraulic chute



1. leveling lattice; 2. speed regulator; 3. pump; 4. connecting pipe for delivery of the indicator; 5. the building model; 6. working area; 7. hydraulic chute; 8. level regulator.

The size of the chute is 3.5 x 0.8 x1.2 m. The side walls are made of glass of 12 mm thickness. The water speed in the hydrochute is regulated on the account of changes in water consumption through the valve. A lattice is put in the front part of the chute to align the speed field. The building model is determined in special working area.

The mixture of chlorbenzene with paraffinic oil is given through special connecting pipe for visualization of the flow, whereas the mixture density exactly corresponds to the water density. Zinc oxide is mixed with the indicator for getting exact trajectory of the movement of the particles in the flow during photographing in the qualitative research process of the building streamline.

The motion trajectories of the indicator particles in both the vertical and horizontal flatness are fixed at the same time by two film recorders or cameras. The screen in black color is placed behind the rear wall of the hydrochute in order to provide more contrast picture of the trajectory of the stream in the photographs. The models in the hydrochute is illuminated by the projector having 15 kW power.

As in the case of flat hydraulic chute, the trace of the movement of particles in the determined scale gives the image of the speed vector in the picture.

It is necessary to state that the treatment of the research results in the voluminous hydraulic chute for the purpose of getting qualitative characteristic regime of streamline is labor–consuming. It is necessary to combine and analyze regularly the pictures of the vertical and horizontal projection of the speed field in order to get the speed of the flow in some points. Besides, there are some difficulties in interpretation of obtained results on the strength of the limited possibilities of the pictorial presentation of three-dimensional speed of the field during modeling of the process of the building wind regime in the voluminous hydraulic chute. Therefore, the voluminous hydrochute is used for the following purposes:

- *for modeling of some private tasks of the wind regime research (for example, physical trace of the building);*
- *for substantiation of the correctness of two-dimensional approach during consideration of the building wind regime and the possibility of use of the flat hydraulic chute for its experimental research;*
- *for determination of the boundaries of applicability of flat modeling (for example, two -dimensional flow of the real building if the length of the building is not more than its 10 height)*

One of the devices making possible the voluminous modeling of the wind regime is the aerodynamic pipe. During its use, the method of determination of the parameters of the speed field is simpler than during the research in the voluminous hydraulic chute and is based on direct measurements. The advan tage of modeling of the aerodynamic characteristics of the building area in the aerodynamic pipe also is in the fact that the same mobile environment (air) exists both in the model and the nature, and the generalization of the research results doesn't require any correction from this point of view.

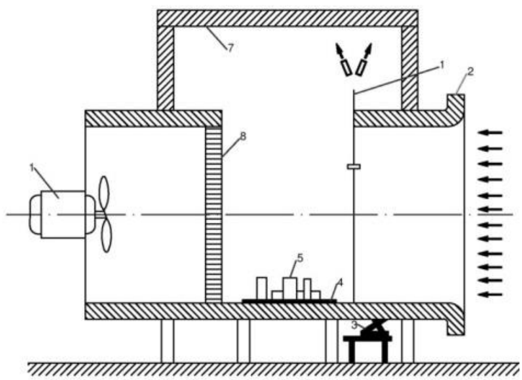
Some shortcomings of the wind regime research in the aerodynamic pipe compared to the hydraulic chute are associated with the difficulties of flow visualization and certain losses of visualization of the research in this connection. Like the voluminous hydrochute, the aerodynamic pipe is widely used to determine the possibility of application of flat modeling of the building wind regime.

But, in certain sense, the study of the speed field is an auxiliary task during research of the wind regime in the aerodynamic pipe, the main purpose is determination of the aerodynamic coefficients of the building in the construction area, since they are the parameters connecting the wind regime of the territory (outside) with the internal microclimate of the building. Both aerodynamic coefficients and the characteristics obtained on their basis are the important parameters which are necessary to be taken into account during evaluation of the building design solution.

The construction of the aerodynamic pipes used to study of the building wind regime and the building aerodynamic characteristics are different enough. A scheme of the experimental plant designed on the basis of the open type aerodynamic pipe is shown in picture 2.7. The pressure overfall stipulating air movement in the working part of the pipe is established through the axial fan activated by the engine of direct current. The use of the engine of direct current gives the possibility to regulate easily the number of turns and accordingly, the speed of the air flow. The air enters into the working part through the damping nozzle. A lattice is put in front of the fan for elimination of the pulsation of the cross section. The rotary table is assembled in the working part of the pipe where the model of the building is determined. The rotary table gives possibility to change the position of the building model with regard to the incident air flow.

It is possible to use copper pipe with the needle of the syringe soldered to its end in order for measuring statistic pressure to the building surface. The tube is connected to the micro-manometer through the medical hose. One more comfortable method of measuring pressure on the surface of the building model is placing inside the models channels going to the surface in the points where the measurement is required. Other end of the channel is contacted with the micro-manometer through the rubber hose or polychlorvinyl tube. In addition, the multi range micromanometer (MMN) which measurement error doesn't exceed 1% from the top limit of the scale can be used for measuring the pressure overfall.

Pic. 2.7 A scheme of aerodynamic pipe for the building wind regime research



1. Pito – Prandtle pipe; 2. sedative nozzle; 3. micromanometer; 4. rotary table; 5. building model; 6. a grid for the alignment of the field speed; 7. working part of the pipe; 8. fan motor.

According to the research results, one important group of features of the wind regime-aerodynamic coefficients of the building are determined using aerodynamic pipe.

In the general cases, the aerodynamic coefficient characterizing a part of the pressure head of air (wind) flow which transforms to pressure on the external surface of the building wall is determined by the following formula:

$$p = k\rho V^2/2 \tag{2.13}$$

where, p - the density of weather, kg\m^3; V -wind speed, m\s; p -pressure of the air flow on the building surface , H\m^2; k – aerodynamic coefficient.

Dimensionless aerodynamic coefficient has positive value depending on whether the given area of surface is located in the zone of wind pressure or suction. Replacement of air happens between the building and the external air under the varieties of pressure on the facade. The values of the aerodynamic coefficients depend on the position of the study surface with respect to the flow, shape and size of the building, as well as design solution of all buildings. Therefore, aerodynamic coefficients allow to evaluate the design solution from the point of view of the extent of influence of the external climatic conditions on the internal microclimate of the buildings.

The average integral value of the aerodynamic coefficient upon the surface of the buildings is determined separately for the pressure head and suction zones:

$$k^+_{ave} = \frac{\sum k_i^+ F_i^+}{\sum F_i^+ + 0.5\sum F_i^0};\ k^-_{ave} = \frac{\sum k_i^- F_i^-}{\sum F_i^- + 0.5\sum F_i^0} \tag{2.14}$$

where, k^+_i and F^+_i -positive values of the aerodynamic coefficient and space of the corresponding area of the building external surface; k^-_i and F^-_i-negative values of the aerodynamic coefficient and space of the corresponding area of the building external surface; F^0_i -spaces of the areas of the building surface with zero values of the aerodynamic coefficients.

The average difference of the aerodynamic coefficients on the opposite façades of the building in the given wind direction is determined as following:

$$\Delta k = |k^+_{ave}| + |k^-_{ave}| \tag{2.15}$$

One else general criterion of the wind regime – generalized aerodynamic indicator H\m$_2$ is included on the basis of determination of the aerodynamic coefficients:

$$A = \frac{\rho}{2}[\Delta k_N(V^N_\infty) \cdot p_N + \Delta k_{NE}(V^{NE}_\infty) \cdot p_{NE} + \cdot\cdot + \Delta k_{NW}(V^{NW}_\infty) \cdot p_{NW}]/100 \tag{2.16}$$

where Δk_N, Δk_{NE}.... Δk_{NW}-the mean values of difference of aerodynamic coefficients on contrary façades of the buildings for eight main wind directions (N, NE, E, NE, S, SW, W, NW); V_∞^N, V_∞^{NE} ... V_∞^{NW} -average wind speed outside the building territory for each wind direction, m\s.

The generalized aerodynamic indicator represents the average pressure difference of the air flow on the contrary façade of the building. Its size characterizes the aerodynamic features of the building as a whole, as well as the features of the wind regime of the construction side (formula 2.16 includes the values of average speeds and repetition of wind on the main eight points).

The variant for which A meets the climatic conditions of the construction side better should be preferred during comparison of the construction versions with different values of aerodynamic indicators. The minimal value of generalized aerodynamic indicators is preferred for cold, windy regions and its maximum value is preferred to warm, low-windy regions.

Different variants are compared on the basis of the average indices for all building groups during optimization of town planning solutions. At that an additional requirement is to minimize the deviation of indicators from the average values for individual buildings, i.e. exclusion of sharp difference in the values of generalized indices of individual buildings:

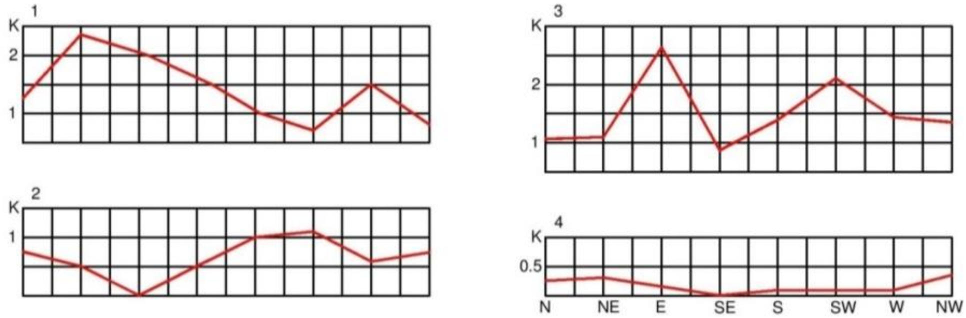
$$A_{gr} = \sum_{i=1}^{N} A_i W_i \ / \ \sum_{i=1}^{N} W_i; \ \sum_{i=1}^{N} \left| A_{qr} - A_i \right| \rightarrow \min \qquad (2.17)$$

where, N-the number of buildings in the construction area; A_i – generalized aerodynamic index for the building, H\m^2; W_i-the volume of ith building, m^3.

The results of the researches carried out on the building of the resort complex (see picture 2.5) is given in picture 2.8. The results of measurement of static pressure on the surface of the building model which treatment is implemented on the formulas (2.13)-(2.15) were used during determination of the aerodynamic coefficients.

The generalized aerodynamic indices of building № 2 calculated on the formula (2.16) using the obtained values of differences of the aerodynamic coefficients are given in table 2.2. The calculation was carried out for climatic conditions of Baku city (p_i and V_{CPi}) characteristic for July for eight main orientations of the building. The largest value of generalized aerodynamic index was recorded in the east-south orientation A_{ES} 55 H\m^2 and the lowest value was recorded in the western orientation A_W = 22,9 H\m^2.

Pic. 2.8. The mean value of the aerodynamic coefficient of opposite facades of the building under different wind directions



The research shows that it shall be oriented so that stronger and more probable wind meets the big value of average weighted aerodynamic coefficient and contrary, for smaller A, more probable and stronger wind shall meet less Δk for achieving more values of general aerodynamic indicator of the building during selection of optimal orientation.

Table 2.2 Values of the aerodynamic indices for building № 2 of the construction complex

Generalized aerodynamic index A,H/m^2	Wind repeatability Pi	Average wind speed V_i, m/s	Building orientation							
			N	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
43,12	0,51	9,6	1,2	1	0,5	0,9	1,4	1,6	1,1	1,2
38,28	0,03	3,9	1	0,5	0,9	1,4	1,6	1,1	1,2	1,2
22,9	0,01	1,9	0,5	0,9	1,4	1,6	1,1	1,2	1,2	1
31,52	0,14	4	0,9	1,4	1,6	1,1	1,2	1,2	1	0,5
48,25	0,11	4,8	1,4	1,6	1,1	1,2	1,2	1	0,5	0,9
55,07	0,02	2,5	1,6	1,1	1,2	1,2	1	0,5	0,9	1,4
40,92	0,02	2,1	1,1	1,2	1,2	1	0,5	0,9	1,4	1,6
41,43	0,16	6,9	1,2	1,2	0,5	0,9	0,9	1,4	1,6	1,1

3. RADIATION REGIME OF BUILDING

3.1. General provisions

The radiation regime of building is determined by the outside conditions (latitude of the place, time of year and day) and the design factors (orientation, form and sizes of the building and their separate parts). The purpose of calculation of the radiation regime is determination of the total heat input from solar radiation on individual parts of the construction area and its elements. Total solar radiation includes: direct solar radiation, diffuse radiation entered from the firmament, the radiation reflected from the earth surface and walling and the Earth emitted radiation.

The density of radiation flow on the surface emitted by the direct solar radiation is determined by the geographic latitude and the position of the surface; the continuation of the irradiation (insolation time) depends on the character of the buildings. The diffuse radiation from the firmament is determined by the character of the building and the openness of the firmament against the irradiated surface area.

The intensity of the secondary flows (reflected radiation and the radiation emitted by heated surfaces) and their distribution on the construction area is determined by: the quantity of entering direct solar radiation, the albedo of the reflecting surface and the orientation of the reflecting, emitting and receiving surfaces. Both the reflected and emitted radiation are the important components of the building radiation regime. The appearance of increased thermal irradiance in the area near the buildings due to thermal irradiance of the building walls and the reflection of radiation from their surface was called "intermia". It was specially brightly expressed in the internal corners of the building inverse to the north horizontal half. Improvement of microclimatic conditions of these areas may be realized through selection of relevant coverage and coloring of walls and consequently, changes of the reflection ability of the wall surface.

The density of the total radiation heat flow entered to the horizontal areas of the building territory and the vertical surface of the building walls is determined according to the following formula:

$$I = I_{dr} + I_r + I_{rr} + Q_t \tag{3.1}$$

where I_{dr}-the density of the direct solar radiation flow, W\m^2; I_r-the density of the diffusive solar radiation flow W\m^2; I_{rr}– the density of the reflected solar radiation flow; W\m^2, Q_t – the density of the thermal radiation flow.

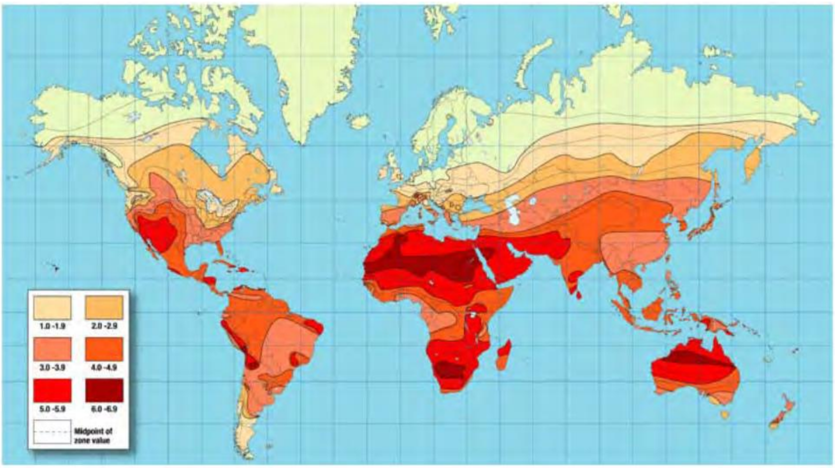
3.2. Solar radiation and orientation

Good orientation increases the energy efficiency of a home, making it more comfortable to live in and cheaper to run. Energy efficiency is finally becoming a mayor item in modern architecture. Due to ever increasing energy prices and the global warming, which is partly a result of the energy production, more and more clients are aware of the necessity to reduce the energy consumption in their buildings. An important clue in developing energy efficient facades is the knowledge about the distribution of solar radiation due to ori entation. At image below the world solar performance regions based on yearly averages of daily hours of sunlight and ambient temperature is shown.

Until recently detailed studies on solar radiation were primarily carried out in the area of solar energy systems, trying to maximize the solar harvest while the trajectory of the sun can be accurately calculated, the incoming radiation depends very much on the actual sky condition: while solar radiation with clear sky and sun can be easily predicted, a cloudy sky complicates this prediction, due to quite different kinds of clouds. (Graph 1)

Map 3.1: This map divides the world into five solar performance regions based on yearly averages of daily hours of sunlight and ambient temperature. Each specific site will, of course, be different Also, local weather conditions and seasonal changes can significantly affect the amount of sunlight available.

(http://www.oksolar.com/abctech/images/world_solar_radiation_large.gif)



To resolve the problem measurements were carried out in the horizontal for many years in many locations worldwide. In order to obtain an idea about the average solar radiation,which is of the utmost importance for the economical analysis of solar systems, the results were interpreted via statistic programs, (Tables 3.1). Many existing software programs for artificial weather data are based on these research results. New programs contribute with calculation mo dules for inclinations up to the vertical to an always more detailed and therefore more exact approach. (CLIMATE CONSULTANT, HEED, OPAQUE and CASANOVA).

- ***Principles of good orientation***

With good orientation the need for auxiliary heating and cooling is reduced, resulting in lower energy bills and reduced greenhouse gas emissions. Build or renovate to maximize the site's potential and to achieve the best possible orien tation for living areas.

In high humid climates and hot dry climates with no winter heating requirements, orientation should aim to exclude sun year round and maximize exposure to cooling breezes. In all other climates a combination of passive solar heating and passive cooling is required, Diagram3.1. The optimum degree of solar access and the need to capture cooling breezes will vary with climate. Where ideal orientation is not possible, as is often the case in higher density urban areas, an energy efficient home can still be achieved with careful attention to design.

Today an in-depth-knowledge on the trajectory and the energetic impact of the sun becomes a major obligation for architects concerned with bioclimatic and sustainable architecture. Introducing tools, which were formerly only used by the "solar energy society", allow architects and planners to perfect the passive building design. They are fundamental tools for the overall layout and influence decisively the orientation of the building (and should influence the master plan, too).

They support the decision of the necessity and/or economy of shading systems, for the reduction of the thermal load by radiation as well as for glare control. The improvement of daylighting generally as well as the application of daylighting devices can be optimized by clear information on the local solar radiation.

Graph 3.1: Monthly average of sky cover TABRIZ city climate in IRAN, (CLIMATE CONSULTANT program result)

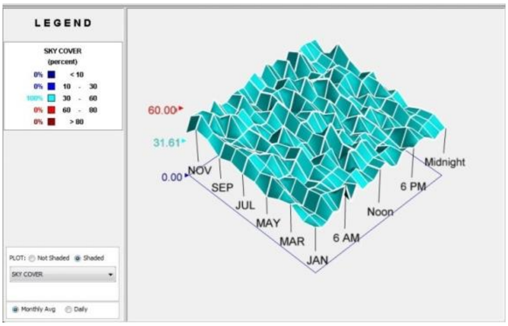
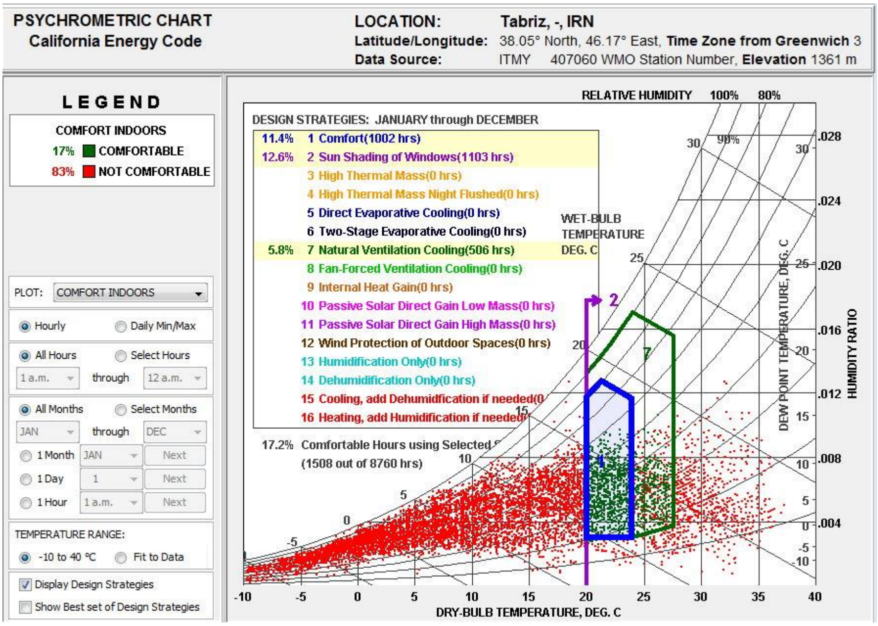


Table 3.1: Monthly means of different climate factors of TABRIZ city climate in IRAN as an example, (CLIMATE CONSULTANT program result)

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	174	253	284	287	333	436	412	378	367	307	238	174	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	130	196	152	102	131	273	237	213	260	269	254	157	Wh/sq.m
Diffuse Radiation (Avg Hourly)	127	165	205	226	251	260	262	251	220	178	137	120	Wh/sq.m
Global Horiz Radiation (Max Hourly)	313	460	522	516	590	764	725	671	661	562	437	302	Wh/sq.m
Direct Normal Radiation (Max Hourly)	163	266	199	127	153	317	276	249	329	349	337	197	Wh/sq.m
Diffuse Radiation (Max Hourly)	232	311	383	410	449	467	471	455	410	342	259	206	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	1688	2664	3363	3744	4696	6365	5913	5087	4501	3368	2370	1641	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	1262	2065	1798	1333	1858	3990	3402	2865	3185	2948	2522	1479	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	1238	1745	2425	2944	3541	3805	3768	3380	2698	1960	1364	1129	Wh/sq.m
Global Horiz Illumination (Avg Hourly)													lux
Direct Normal Illumination (Avg Hourly)													lux
Dry Bulb Temperature (Avg Monthly)	-2	0	5	10	16	21	25	25	21	14	6	0	degrees C
Dew Point Temperature (Avg Monthly)	-7	-6	-1	0	4	6	7	6	4	2	0	-4	degrees C
Relative Humidity (Avg Monthly)	69	69	63	54	48	42	34	33	35	50	66	76	percent
Wind Direction (Monthly Mode)	90	240	60	90	90	90	60	90	60	110	60	70	degrees
Wind Speed (Avg Monthly)	2	3	2	3	2	3	5	2	2	2	1	1	m/s
Ground Temperature (Avg Monthly of 3 Depths)	3	2	2	4	10	15	19	20	20	17	12	7	degrees C

Diagram3.1: Natural ventilation cooling role in passive design at TABRIZ city climate in IRAN (CLIMATE CONSULTANT program result)

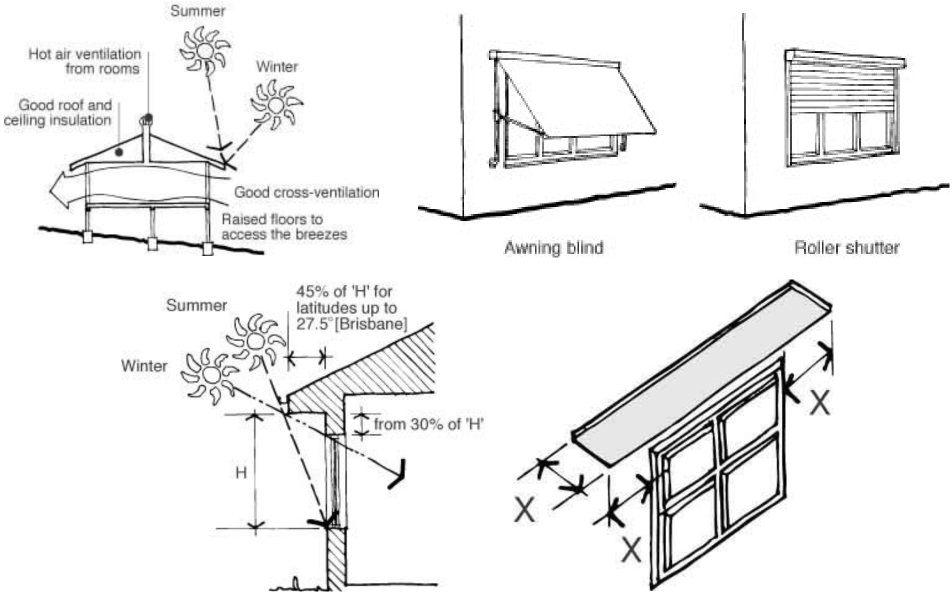


The definition of the wall materials and the necessary thermal insulation system relates on this information. As modern architecture is still suffering by the internationalist approach, multiplying design ideas without paying any respect to regional climate and culture, an exact, scientifically correct prevision of the buildings. Behavior might support significantly intelligent decisions for a sustainable architecture, or the "regional modernism".

- ***Orientation for passive heating***

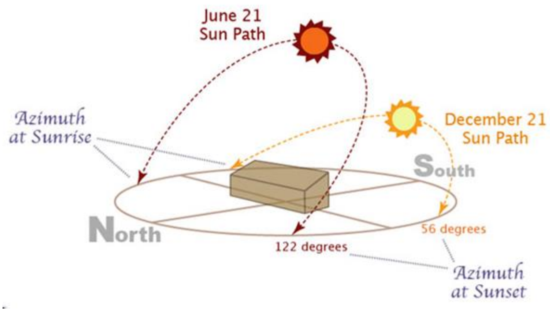
Orientation for passive heating is about using the sun as a source of free home heating. Put simply, it involves letting winter sun in and keeping unwanted summer sun out. This can be done with relative ease on northern elevations by using shading devices to exclude high angle summer sun and admit low angle winter sun.

Schema 3.1: Different ways of shadowing system by using fixed and movable devices



'Solar Access' is the term used to describe the amount of useful sunshine reaching the living spaces of a home. The desired amount of solar access varies with climate.

Pic 3.1: Maximizing south facing of building in cold climates



Various techniques are available for measuring solar access when designing a new home or renovating, to ensure good solar access without compromising that of neighbours. These techniques include computer programs, charts and formulas. (Diagram 3.1 and 3.2)

We can achieve good passive solar performance at minimal cost if your site has the right characteristics. Where possible, choose a site that can accommodate north-facing daytime living areas and outdoor spaces. Permanent solar access is more likely to be achieved on a north-south block. However, on narrow blocks, careful design is required to ensure sufficient north facing glass is included for adequate passive solar heating.

Diagram 3.1: Sun shading chart of Tabriz city in Iran during winter-spring seasons (CLIMATE CONSULTANT program result)

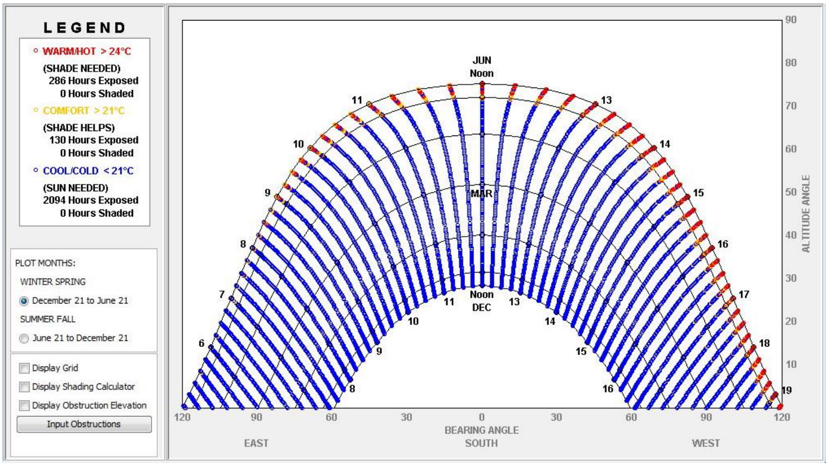
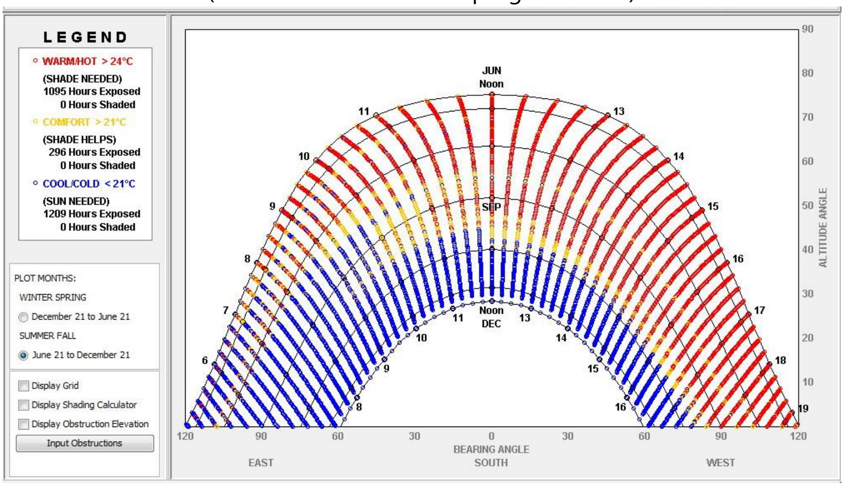


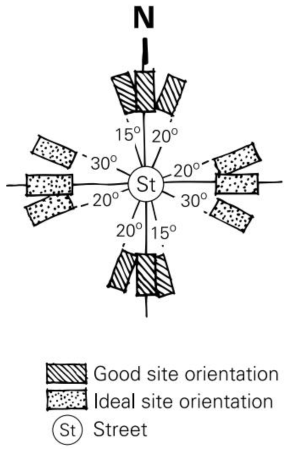
Diagram 3.2: Sun shading chart of Tabriz city in Iran during summer-fall seasons (CLIMATE CONSULTANT program result)



The site

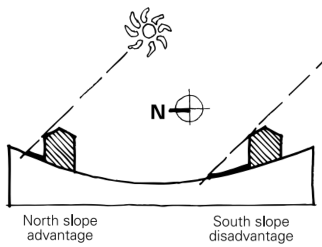
Sites running N-S are ideal because they receive good access to northern sun with minimum potential for overshadowing by neighbouring houses. In summer neighbouring houses can provide protection from low east and west sun. N-S sites on the north side of the street allow north facing living areas and gardens to be located at the rear of the house for privacy. N-S sites on the south side of the street should be wide enough to accommodate an entry at the front as well as private north facing living areas. Set the house back to accommodate a north facing garden. Sites running E-W should be wide enough to accommodate north facing outdoor space. Overshadowing by neighbouring houses is more likely to occur on these sites.

Schema 3.2: Suitable orientation for heating

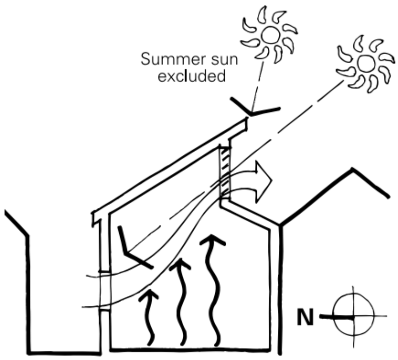


A north facing slope increases the potential for access to northern sun and is ideal for higher housing densities. A south facing slope increases the potential for overshadowing. Views to the north are an advantage, as north is the best direction to locate windows and living areas. If the view is to the south avoid large areas of glass in order to minimise winter heat loss. West or east facing glass areas will cause overheating in summer if not properly shaded.

Schema 3.3: Slope and maximum solar radiation absorption

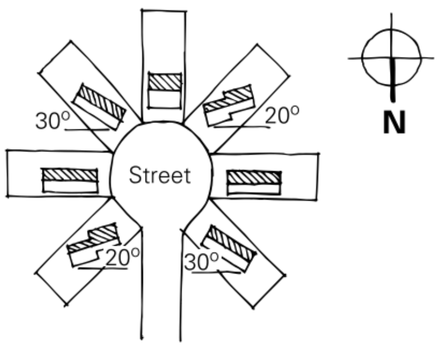


Schema 3.4: High level openable windows capture winter sun and create cooling currents in summer



On sites with poor orientation or limited solar access due to other constraints, an energy efficient home is still achievable through careful design. A larger bud get may be required. Use of advanced glazing systems and shading can achieve net winter solar gains from windows facing almost any direction while limiting summer heat gain to a manageable level. The ideal orientation for living areas is within the range 15ºW-20ºE of true or 'solar' north. (20ºW-30ºE of true north is considered acceptable). This allows standard eave overhangs to admit winter sun to heat the building and exclude summer sun, with no effort from the occu pants and no additional cost. Poor orientation can exclude winter sun, and cause overheating in summer by allowing low angle east or west sun to strike glass surfaces.

Schema 3.5: Living spaces solar access relation with orientation (Day time living areas shown shaded)

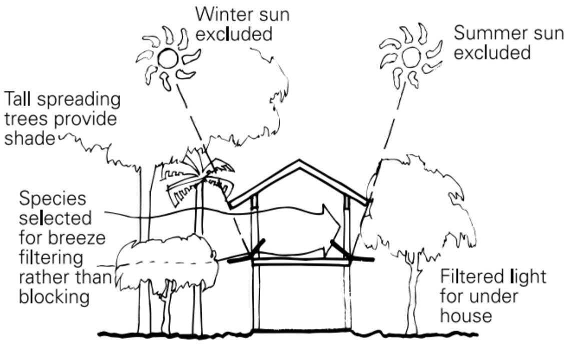


- ***Orientation for passive Cooling***

Good orientation for passive cooling excludes unwanted sun and hot winds and ensures access to cooling breezes. In high humid climates and hot dry climates with warm winters, direct and reflected sunlight should be excluded at all times of the year. In all other climates a degree of controlled solar access is beneficial.

Solar access is beneficial for solar collectors, clothes drying and vegetable gardens in all climates. On sites with poor orientation or no access to cooling breezes an energy efficient home is still possible with good design. Use high level windows and vents to create convection currents for cooling in the absence of breezes. Landscape and building form can be designed to deflect and control the flow of breezes or to block unwanted sun.

Schema 3.6: Shading by using landscape in hot humid climates



- ***Direct and diffuse radiation***

Another important aspect of the solar radiation is the ratio of diffuse and direct radiation, Diagram 3.3, 3.4, 3.5 and 3.6. While direct radiation can –more or less easily – be blocked out by shading devices or redirected to improve daylighting in the depth of the buildings, diffuse radiation is in some way more difficult to handle, especially if one works with passive systems. Depending on the location, (TABRIZ city in IRANas an example) diffuse radiation might have a more important impact on the architectural layout than direct radiation. Especially locations in the hot-humid tropics and cold climates.

Close to the equator are facing a very high degree of diffuse radiation.

proper landscaping, limiting the horizon as well as low angle reflections, and with traditional shading devices, high rise buildings are more difficult to be adapted: the mostly used solution reflective or absorptive glazing might diminish the glare problem, but parallel reduces the daylighting quality of the façade drastically. Due to the fact that in cold climate regions the diffuse radiation has a predominant share of the overall radiation and the fact that the distribution of the diffuse radiation is almost identical at all orientations, the orientation of the buildings might be more influenced by other external aspects, like e.g. the prevailing wind direction.

Diagram 3.3: Hourly diurnal averages of global horizontal direct, normal and diffused solar radiation of TABRIZ city in IRAN (as an example) (CLIMATE CONSULTANT program result)

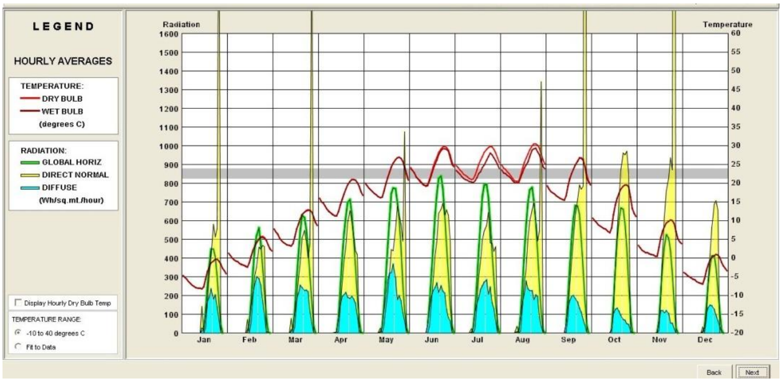


Diagram 3.4: Hourly averages of monthly directed and global horizontal solar radiation of TABRIZ city in IRAN (CLIMATE CONSULTANT program result)

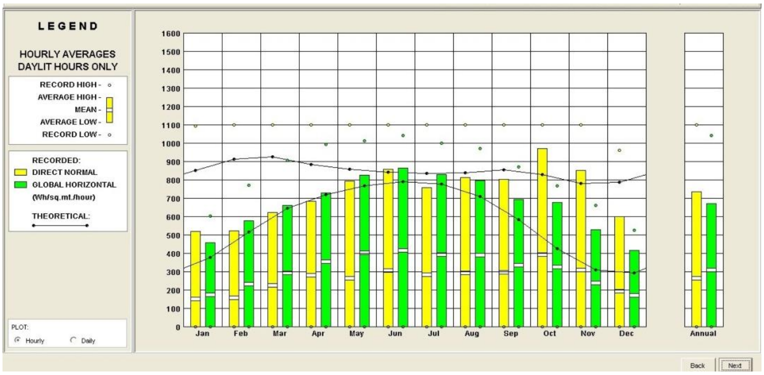


Diagram 3.5: Direct normal radiation example in TABRIZ city in IRAN (as an example) (CLIMATE CONSULTANT program result)

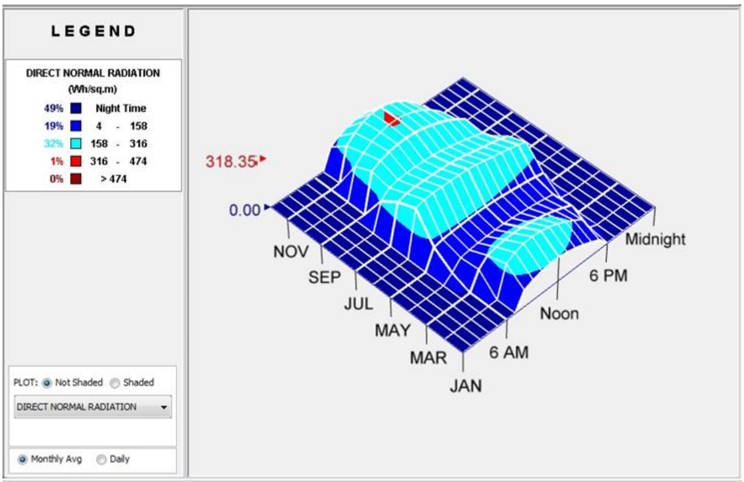
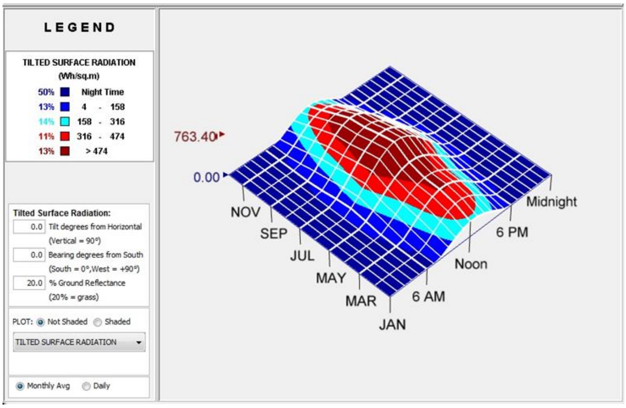


Diagram 3.6: Tilted surface radiation (20% reflected from grass coverage) example in TABRIZ city in IRAN (as an example) (CLIMATE CONSULTANT program result)



3.3. Calculation and experimental determination of the direct solar radiation

The duration of irradiation of different areas of the constriction territory (insolation time) and the quantity of entered solar radiation are determined when solar radiation is calculated. According to the calculation results, two types of insolation maps are developed: the isolines of insolation continuation is applied in one map and the isolines of the quantity of heat input from direct solar radiation is applied in other map. These maps are useful not only for estimation of general heat regime of the building which is implemented taking into account other climatic impacts, but also during the decision of a number of tasks of architectural design including selection of distance between the buildings, placement of sports and children's playgrounds, pollens, basins, foot paths and so on. The maps are also necessary for controlling the requirements of normative documents regulating the building insolation, though these requirements are restricted enough.

At the present time, the graphical calculating methods of insolation of the building via insographs are widely used. As a rule, insograph consists of two line systems (picture 3.1):

1. *Curves, which are the projection on the horizontal plane of intersections of the surfaces S describing the sun beams directed to the design point O within a day with horizontal plane F that is removed from the earth surface on the given distance H (the height of shading buildings). It is possible to show that these curves coincide with the trajectories of the shadows from the end of the rod at the height H during daily movement of the Sun (picture 3.1 a).*
2. *Clock radial lines representing the horizontal projection of the sun beams directed to the design point O at different fixed moments of day (picture 3.1 b).*

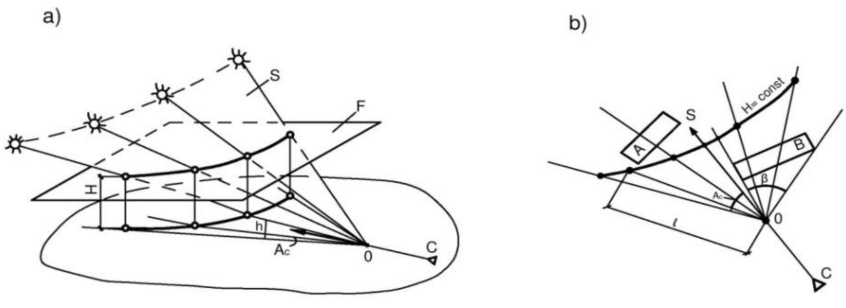
Insograph is constructed for certain latitudes and times of year, wherein the tabular data of the corner coordinates of the Sun are used: height *h* and azimuth A_c. A_c and l=H\ctg*h*M are the polar coordinates in the insograph with the center in the design point O and the beginning of calculation from the south direction, where M is the scale of linear dimensions. If to include the construction plan of the same scale in the insograph, it is easy to determine whether one or another building influences the insolation in the point O. From two buildings A and B having the same height H (picture 3.2), the building A doesn't influence the irradiation of the design point of building B for a time when the Sun passes to corner β and shades point O.

Insograph looks especially simpler for equinox-March 22 and September 22-curves corresponding to the same height H of the sun beam on the horizontal plane pass to the straight lines. The mean values of the flows of straight and diffuse radiations for corresponding hours are shown for calculation of heat input from the radiations between the hour projections of the sun beams.

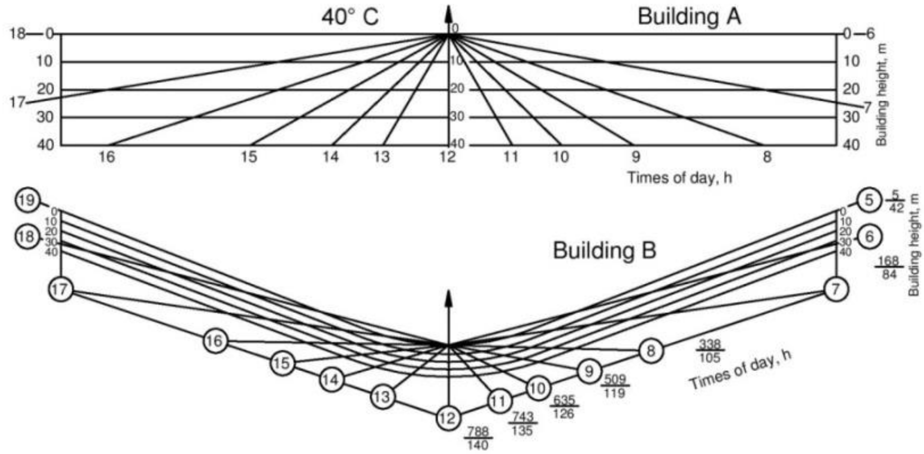
Two types of insograph are widely used:

1. With fixed height of the shaded constructions. The set of curves on the graphs corresponds to different months of year. The advantage of these graphs is the possibility of implementation of calculations for any month of the year and the disadvantage is that every graphic is valid for the shaded objects having the same height. In a special device known as light plan-meter of V.A. Maslennikov [3, 4] an insograph with additional lines put to the transparent material constructed on the basis of this insograph. The duration of insolation of different areas of the building is determined by putting the light plan-meter on the building plan and the quality of thermal radiation is determined through special transparent attachable discs. Every device is considered only for one height of the shaded object. Some light plan-meters corresponding to different heights of the building are required for the analysis of multistory buildings.

Pic. 3.1 Scheme of the insograph construction



Pic. 3.2 Insograph for calculation of continuation of insolation and heat input from the solar radiation for days (Scale 1:1000)



a – March 21 and September 21; b – June 21 (above the line – value of straight solar radiation falling to the horizontal surface, below the line –diffused W\m²)

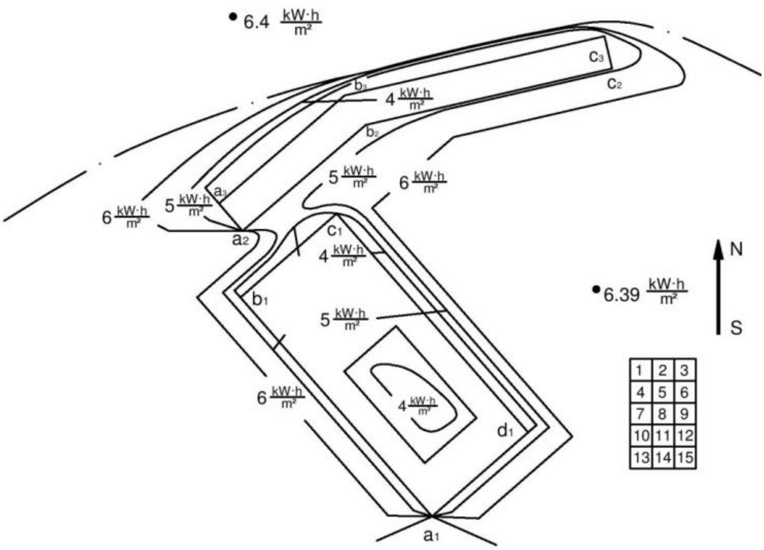
2. Insograph with fixed times of year. The set of curves on the graphics corresponds to different heights of the shaded constructions. Such kind of insograph gives possibility to analyze multistory building for certain time of year. Special insolation tablets and lines have been developed by researchers on their basis [5].

During analysis of the building insolation regime all of its territory is divided into a range of same small areas, the sizes of which shall be selected that the insolation period from point to point changes insignificantly. The design point of insograph shall coincide with the central point of the analyzed area, wherein the orientation of the insograph must correspond to the building plan. The radiation intensity in a point of construction territory for fixed time is determined according to tables. It is comfortable to record the results of the researches on the building insolation regime in a form of table (table 3.1 and 3.2).

The data presented in tables allow to construct the buildings on the plan of the construction territory using the interpolation of isoline of the insolation continuation (the lines, which every point is insolated with the same hour numbers) and isoline of quantity of direct radiation lines (the lines, which every point has the same general total radiation inputs for all insolation).

General characters of the insolation of the territory, critical points with increased level of the radiation heat input are determined and architectural planning, solar control and other measures are implemented for the purpose of normalization of microclimate of the building territory based on analysis of such maps.

Pic. 3.3. Isolines of duration of insolation of the construction area in July



The tables also allow to define some general characters of the insolation of the territory (these characters are considered on the example of the court yard territory of the building of the medical rehabilitation center of Sport Palace in Baku city, picture 3.3 and table 3.2).

The total heat input, W·hour\m^2 for *k* area of the territory within a day (lower part of the table 3.2) due to the direct solar radiation is equal to the following:

$$I_{dr}^{k} = \sum_{i=1}^{N} I_{dri}^{k} \qquad (3.2)$$

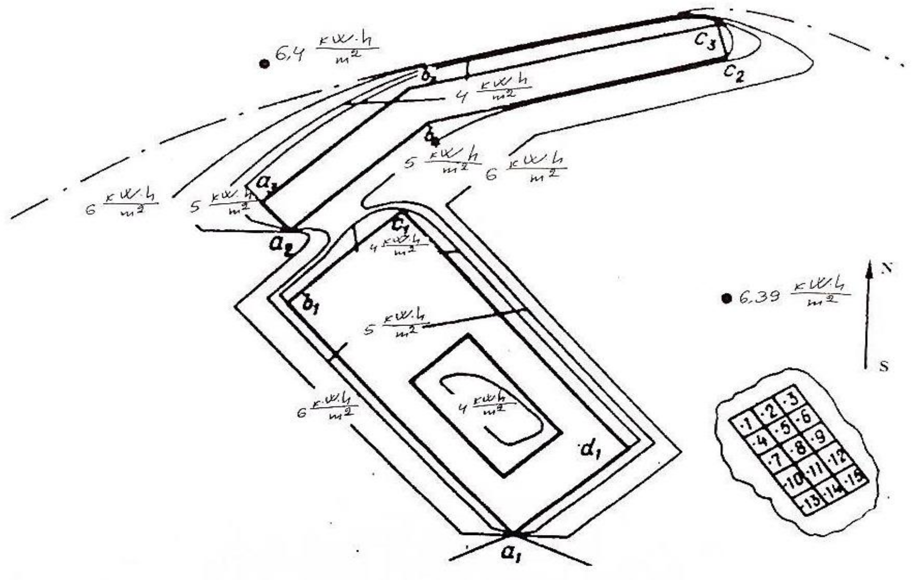
where, $I^k_{dr.}$-the intensity of the direct solar radiation on *k* territory at *i* moment of time, W\m^2; *N* – insolation period, hour.

Table 3.1. The density of the direct solar radiation flow on different parts of the construction territory, W/m^2 (pic. 3.3)

Site №	Times of day, h														Time of site insolation..,h	Total radiation of site, W/m^2
	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19		
1	56	168	338	509	635	743	788	788	743	635	509	338	168	-	13	6418
2	56	168	338	509	635	743	788	788	743	635	509	338	-	-	12	6250
3	56	168	338	509	635	743	788	788	743	635	509	-	-	-	10	5403
4	56	168	338	509	635	743	788	788	743	-	-	-	-	-	8	4025

5	-	-	-	-	635	743	788	788	743	635	509	338	168	56	10	5403
6	-	-	338	509	635	743	788	788	743	635	509	338	168	56	12	6250
7	-	168	338	509	635	743	788	788	743	635	509	338	168	56	13	6418
8	-	168	338	509	635	743	788	788	743	635	509	338	168	56	13	6418
9	-	-	338	509	635	743	788	788	743	635	509	338	168	56	12	6250
10	-	-	-	-	635	743	788	788	743	635	509	338	168	56	10	5403
11	-	-	-	-	-	-	788	788	743	635	509	338	168	56	8	4025

Pic. 3.4. Isolines of the direct solar radiation daily input on the construction area in July



The share of the insolated territory of the building (%) at *i* hour (graph 17, table 3.2) is equal to:

$$n_i = \left[\left(\sum F_k^{ins}\right)/F\right]100 \qquad (3.3)$$

where, F^{ins}_k– the insolated k^{th} area of the territory, m^2; F – total area of the building, m^2.

An average value of the percentage of the insolated territory within the insolation period of the building N is equal to:

$$n_{av.} = \left(\sum_{i=1}^{N} n_i\right)/N \qquad (3.4)$$

where for the courtyard N =14 hours (from 5:00 to 19:00); $n_{av.}$ = 51.6 %.

Maximum percentage of the insolated territory within a day (for courtyard n_{max}=100%). Total heat input (W·h) of the direct solar radiation per a day is:

$$Q_{sr} = \sum_k I_{sr}^k F_k = I_{sr_i}^k F n_{sr} \qquad (3.5)$$

For the courtyard $Q_{dr.}$ = 66 988 W· hour = 67 kW · hour.

Table 3.2 The density of the direct solar radiation flow (W\m^2) on different areas of the courtyard in July (pic. 3.4)

Times of day h-min.	Site number															The share of the insolated territory, n_i, %
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
5-5.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
5.30-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
6-6.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
6.30-7	168	-	-	168	-	-	168	-	-	168	-	-	-	-	-	27
7-7.30	338	-	-	168	-	-	338	-	-	338	-	-	-	-	-	27
7.30-8	338	338	-	338	308	-	338	338	-	338	308	-	-	-	-	53
8-8.30	509	509	-	338	509	-	509	509	-	509	509	-	-	-	-	53
8.30-9	509	509	-	509	509	-	509	509	-	509	509	-	-	-	-	53
9-9.30	635	635	635	509	635	635	635	635	635	635	635	-	-	-	-	80
9.30-10	635	635	635	635	635	635	635	635	635	635	635	-	-	-	-	80
10-10.30	743	743	743	635	743	743	743	743	743	743	743	-	-	-	-	80
10.30-11	743	743	743	743	743	743	743	743	743	743	743	743	-	-	-	80
11-11.30	788	788	788	743	788	788	788	788	788	788	788	788	-	788	788	100
11.30-12	788	788	788	788	788	788	788	788	788	788	788	788	788	788	788	100
12-12.30	788	788	788	788	788	788	788	788	788	788	788	788	788	788	788	100
12.30-13	788	788	788	788	788	788	788	788	788	788	788	788	788	788	788	100
13-13.30	-	743	743	788	743	743	-	743	743	-	743	743	788	743	743	67
13.30-14	-	743	743	-	743	743	-	743	743	-	743	743	-	743	743	67
14-14.30	-	635	635	-	635	635	-	635	635	-	635	635	-	635	635	67
14.30-15	-	635	635	-	635	635	-	635	635	-	635	635	-	635	635	67
15-15.30	-	-	-	-	509	509	-	509	509	-	509	509	-	509	509	53
15.30-16	-	-	-	-	509	509	-	509	509	-	509	509	-	509	509	53
16-16.30	-	-	-	-	-	338	-	338	338	-	338	338	-	338	338	53
16.30-17	-	-	-	-	-	338	-	338	338	-	338	338	-	338	338	53

Table 3.2 (continued). The density of the direct solar radiation flow (W\m^2) on different areas of the courtyard in July (pic. 3.4)

Times of day h-min.	Site number															The share Of the Insolated territory, n_i, %
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
17-17.30	-	-	-	-	-	-	-	-	168	-	-	168	-	-	168	20
17.30-18	-	-	-	-	-	-	-	-	-	-	-	168	-	-	168	13
18-18.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
18.30-19	-	-	-	-	-	-	-	-	-	-	-	-		-	-	0
The time Of Site insolation, h	6,5	7,5	6	6,5	9,5	8	6,5	9,5	8,5	6,5	9,5	9	2	6	7	-
The sum Of direct radiation entering per day, $^{i}_{dr}$, W·h/m^2	3885	5010	3732	3885	5887	5179	3885	5857	5263	3885	5857	5347	1576	3801	3969	-

The radiation regime of the construction complex is determined not only by the radiation to the earth surface, but also the radiation falling on the exterior fencing structures, since these surfaces become the sources of both reflected and heat radiations. Experimental in –situ researches show that for example, in the southern cities the influence of the reflected radiation and the radiation emitted from surfaces appear in the following distances from the surface: at south-eastern and southern orientations up to 4-5m, south-western orientation-7-8m, eastern orientation-9-10 m, north-western orientation-5-6 m. The walls facing to the east and south-east are under more favorable conditions, as high intensity of their radiation is usually coupled with highest daily air temperature.

The duration of buildings' facade insolation and consequently, the quantity of the direct solar radiations to the wall may also be determined using inso graphs. The insolation time is determined by putting the insograph on the construction plan and mixing its design point with the relevant points on the building façade. The heat input from the direct solar radiation is determined using the table of heat input from solar radiation for a vertical surface oriented suitably.

The density of the direct solar radiation flux on the vertical surface of walls $I^{V}_{dr.}$ may be also determined according to the following formula:

$$I_{dr}^{V} = I_{dr}^{Q} \cot h \cos(|A_S - A_0|) \tag{3.6}$$

where I_{dr}^{V}-the density of the direct solar radiation flow on horizontal surface, W\m^2, h-height of the Sun, grad; A_s-azimuth of the Sun, grad; and A_o –azimuth of the wall (corner between normal to vertical surface of the wall and in the southern direction).

The azimuth of the Sun and the wall surfaces is calculated from the south direction and changes from 0 to ±180º, wherein the western azimuths are considered positive and eastern azimuths are considered negative.

The use of the formula (3.6) is necessary for voluntary orientation of the building when the data on the radiation to the vertical surfaces are absent.

Calculation of insolation of the facades may be implemented directly by the formula (3.6) without using insograph (table 3.3, see picture 3.4) for the walls not shaded by the buildings located at short distance.

The graphical methods of evaluation of the insolation conditions of the buildings and territory (using insographs, light plan-meters and so on) cause some difficulties during designing the construction site with the buildings of different storey and complex configurations, because they are time consuming. However, it is impossible to analyze graphically some of the building areas. In these cases, it is expedient to use the method of modeling of the insolation conditions on the building models [4]. According to the principle of action, they can be divided into:

- *the devices where the table under the model remains immovable and the light source (artificial sun) is moved according to the given trajectory;*
- *the devices where the table under the model stands on hinges supplied by calibrated limbs and scales for installation at the required time of day and year and the light source is fixed immovable;*
- *the devices with combined action principles.*

The device developed for insolation modeling in the scientific-research institute of Construction Physics consists of the following principal parts:

1. "artificial sun" -projector with parabolic mirror reflector (d=0,9m) in the protective cover in the angle bar with counterbalance moved in the ver tical plane around the horizontal axis using the manual mechanism. The inclination of the bar of the projector is controlled on the scale of the vertical corners of the sun from 0 to 90º;
2. "artificial earth"-the rotary table (rotates in the horizontal plane around the vertical axis) with graduated azimuth corners from 0 to 180º counted from the southern direction;
3. control mechanism.

The insolator is supplied by special bracket for fastening of the camera in zenith position above the insolated model of the construction that allows taking records of the daily variation of insolation of the studied building or town – building situation.

It is known that true parallelism of the beam lights from the projectors is determined at the distance not less than 800 meter. However, as the laboratory experiments showed, the shadows of vertical bars have the parallelism enough for the purposes of the experiment in the area of a circle of the table top with 0.9 meter diameter and at a 2.5 m distance.

The method of working on the "insolator" is as following: "The artificial sun" is taken using the hand drive in zenith position. The rotary table top is determined exactly as in the beam of the projector (the light spot coincides with the cover of the table). The arrow (the pointer of azimuth corners of the table) must be placed on the plane of the projector motion and directed to the projector in the position 0° (horizontal position of the bar). The table top is put in the position 0° of the graduated azimuth corners.

Table 3.3. Heat input of the direct solar radiation $I^{h}_{dr.}$,W\m^2 on the external surfaces of the building walls (at 40°, July)

Hours of the day	The azimuth of the Sun, As, grad	ctg h	$I^{h}_{dr.}$, W/m^2	The density of direct solar radiation flux on the outer surfaces of walls of buildings, W/m^2, under A_0 azimuth of wall, grad									
				44 (a_1b_1)	134 (b_1c_1)*	- 134 (c_1d_1)	- 44 (d_1a_1)	- 44 (a_2d_2)*	- 17(b_2c_2)	- 107 (c_2c_3)	163(c_3b_3)	134(b_2a_3)	44(a_2a_3)
5-6	-112	5,5	56	-	-	285	115	115	-	307	27	-	-
6-7	-103	2,6	168	-	-	374	224	224	30	435	-	-	-
7-8	-94	1,6	338	-	-	414	347	347	122	256	-	-	-
8-9	-85	1,05	509	-	-	351	403	403	200	495	-	-	-
9-10	-73	0,68	635	-	-	209	378	378	241	358	-	-	-
0-11	-55	0,45	743	-	-	64	327	327	263	206	-	-	-
11-12	-23	0,34	788	60	-	-	250	250	267	-	-	-	60
12-13	23	0,34	788	250	-	-	60	60	205	-	-	-	250
13-14	55	0,45	743	327	64	-	-	-	103	-	-	64	327
14-15	73	0,68	635	378	209	-	-	-	-	-	-	209	378
15-16	85	1,05	509	403	351	-	-	-	-	-	111	351	403
16-17	94	1,6	338	347	414	-	-	-	-	-	193	414	347
17-18	103	2,6	168	224	374	-	-	-	-	-	218	374	224
18-19	112	5,5	56	115	285	-	-	-	-	-	194	285	115
				Σ=2104	Σ=1697	Σ=1697	Σ=2104	Σ=2104	Σ=1431	Σ=2327	Σ=743	Σ=1697	Σ=2104

The insolation condition of the building is modeled through illumination of the model by the beams of the “artificial sun” installed with the angular coordinates relative to the model corresponding to the given hours of a day, month of year and geographical latitude.

The coordinates of the Sun (azimuth and angular height, grad) for every hour of the daylight time of the day on 12 months of year for the geographical latitude from 35 to 70° through 5° are given in a special table attached to installation.

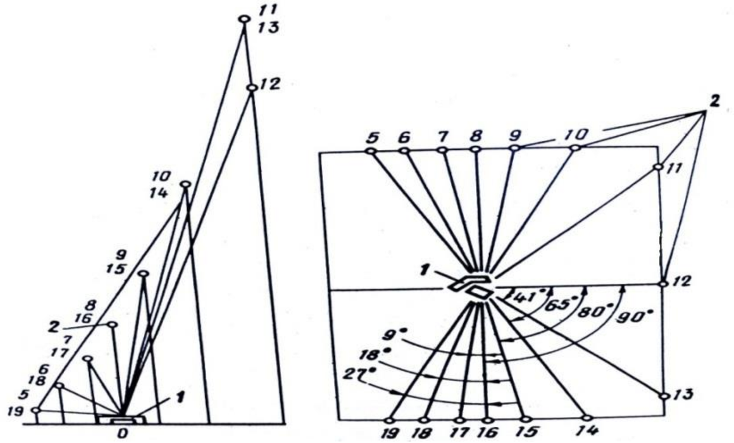
The insolation picture for every hour position of the Sun is fixed either during photographing or on the marked points using specially prepared forms. The latter presents a table including in the vertical column insolation conditions of each point. The insolation condition of the point in the given hour is marked by the following manner: “+” – the point is insolated, “-” – the point is not insolated.

After implementing experiments, the insolation conditions of every marked point are determined according to the given table and the degree of the conformity of insolation with the given town-building situation is checked. Both the course of “light and shadow” gradation on the building facades and the efficiency of the solar protecting devices can also be estimated on the installation.

Some other principles of the building insolation modeling are realized at the laboratory device called “Fixed sun” [4].

Instead of mechanical reproduction in insolator, this device records the Sun position for every hour of a specific day of year.

Pic. 3.5. Assembling diagram of "Fixed sun" device
(the hours of day are marked by numbers)



The "Fixed sun" works in the following manner: the azimuths of the Sun are set aside for every hour of a concrete day of year from the fixed point O from the conditional southern direction. The height of the Sun is set aside in the vertical plane from the azimuth line. The lamps are installed in the given points.

The model of the building is installed in a point O to study insolation. Complete picture of the building insolation can be obtained by both on its continuation and the area through successive switching on the lamp. The scheme of the device modeling the insolation condition for June at a 40° latitude is shown in picture 3.5.

3.3 Calculation of the diffuse radiation

The heat input from diffuse radiation to different areas of the construction territory and to the surface of the building walls may be determined by the following formula:

$$I_{dif} = I^{h}_{dif} K_{ir} \tag{3.7}$$

where I_{dif} -the density of the flow of the diffused solar radiation on the horizontal surface at open horizon, Wt\m^2; K_{ir} – coefficient of irradiation of the surface by the firmament of the given area (takes into account the decrease of the diffuse solar radiation input as the result of "shading" of the firmament by the construction elements).

At the open horizon the irradiation coefficient for the surface of the earth K_{ir}=1 and for the surface of the wall K_{ir}=0.5 (taking into account the fact that the half of the firmament is closed by wall).

Generally, K_{ir} for an area in the construction territory is determined by the following formula:

$$K_{ir} = 1 - \sum_{i=1}^{N} \varphi_{c-w}^{i} \tag{3.8}$$

where φ^{i}_{c-w}– the irradiation coefficient of the element on the earth surface with i^{th} surface of the wall, N-general number of the surfaces of the walls of the building closing the horizon for the considered element on the earth surface.

Since the external surfaces of the building walls are flat as a rule, so only two calculation diagrams of irradiation of the area by the building wall may be appeared during determination of φ^{i}_{c-w}in the practice (picture 3.6).

Then the irradiation coefficient may be determined by the following formula:

For case a) $\varphi_{c-w} = f(X_1, Y_1) + f(X_2, Y_2)$ (3.9)

For case b) $\varphi_{c-w} = f(X_2, Y_2) - f(X_1, Y_1)$ (3.10)

$$f(X, Y) = \frac{1}{2\pi}\left[\operatorname{arctg}\left(\frac{1}{Y}\right) - \left(\frac{Y}{\sqrt{X^2+Y^2}}\right)\operatorname{arctg}\left(\frac{1}{\sqrt{X^2+Y^2}}\right)\right]$$

$$X_1 = \frac{a}{b_1};\ X_2 = \frac{a}{b_2};\ Y_1 = \frac{c}{b_1};\ Y_2 = \frac{c}{b_2} \tag{3.11}$$

The results of the calculation by the formula for the areas of the surface having different remoteness from the building facade a_1d_1 *(*see picture 3.4) are provided below: *a* = 9.9 m; b_1=b_2= 21 m; C = 1 – 100 m.

Distances from facade, m 1 2 5 10 20 100

φ_{c-w} 0,44 0,4 0,258 0,138 0,016 0

K_{ir} 0,56 0,6 0,742 0,862 0,984 1

Diffuse radiation

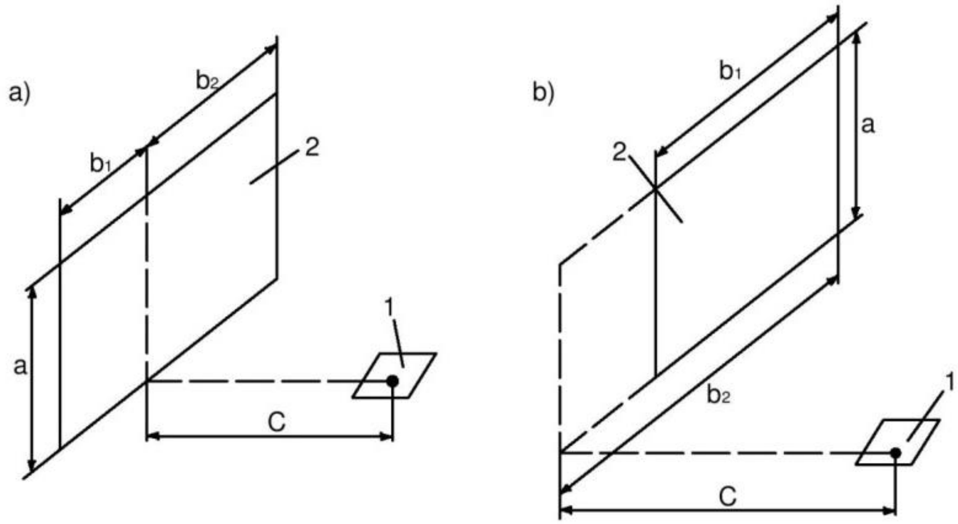
flow,I_{dif} W/m^2 .... 67 71 88 103 117 119

The irradiation coefficient of the external surface of walls can be determined by the following formula:

$$K_{ir} = 0{,}5 - \sum_{i=1}^{N} \varphi_{w-wi}^{i} \tag{3.12}$$

where φ_{w-wi} – the irradiation coefficient of the considered wall surface by the surfaces of the walls covering horizons.

Pic. 3.6 Calculation schemes for determination of the irradiation coefficient of mutually irradiated surfaces of the earth –1 and the building walls – 2



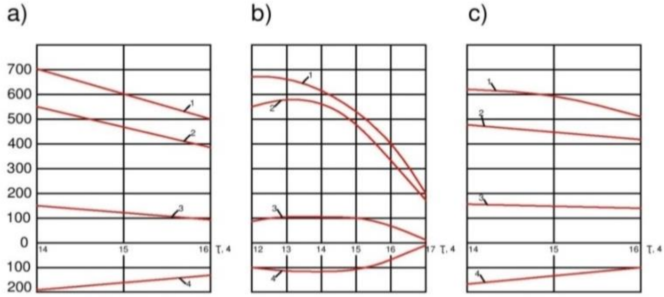
The irradiation coefficient may be determined for example, according to (17) for parallel and mutually perpendicular placing of mutually irradiated surfaces. The horizon is free for facade a_1d_1 considered above (see picture 3.4), therefore $K_{ir.}$ = 0/5 and accordingly, $I_{dif.}$ = 0,5 ·119 = 59,5 W\m^2.

3.4 Determination of the heat gain from the reflected solar and thermal radiations

As the in-situ researches show, reflection of the solar radiation and thermal irradiation of the surface is an essential factor determining the radiation and thermal regime of building.

The radiation reflected from the horizontal surface of the earth (with albedo 30-40%) significantly changes both the irradiation condition of the ver tical surface of the wall and the quantitative correlations between the irradiation of separately oriented surfaces. The vertical surface "sees" not only half of the firmament, but also half of the earth and the albedo of the earth, as a rule, is significantly large than the conditional albedo of the sky. Therefore, complete radiation presents the sum of the diffuse radiation coming from the firmament and the radiation reflected from the earth. The data derived from in-situ measurements of the solar radiation intensity (direct, diffuse, complete and reflected) implemented in the regions of Azerbaijan are given in picture 3.7. Diffused and reflected radiations are nearly commensurable, but in some cases the radiation reflection is higher.

Pic. 3.7 Solar radiation intensity at the height of 0,5 m from different underlying surfaces (Azerbaijan, Kurdemir region)



a-bare soil, b-grass, c-asphalt; 1-complete radiation, 2-direct, 3-diffuse, 4-reflected.

Under the town building conditions in the southern cities where white surfaces dominate, lower part of the firmament is enclosed from underlying surface with walls having albedo exceeding the conditional albedo of the firmament for several times. It significantly increases the intensity of the total radiation on the earth surface near the walls.

The experiments show that the reflected diffuse radiation is spread over all directions equally obeying the Lambert law. It allowed to suggest the engineering method of calculation of the reflected radiation [6] according to which the densities of the reflected radiation fluxes received at the earth surface in the construction area $I^{c}_{ref.}$ and the wall surface $I^{w}_{ref.}$ can be determined by the following formula:

$$I^{c}_{ref} = \sum_{i=1}^{N}(I^{\Sigma}_{ref}A_i\varphi_{ti}) \qquad (3.13)$$

$$I^{w}_{ref} = \sum_{i=1}^{N-1}(I^{\Sigma}_{ref}A_i\varphi_{wi}) + I^{\Sigma}_{c}A_c\varphi_{w-c} \qquad (3.14)$$

where I^{Σ}_{w} – the density of the total solar radiation on the i^{th} surface of the building wall, W\m^2; I^{Σ}_{c} – the density of the total solar radiation on the earth surface, W\m^2; A_i-albedo (radiation reflection coefficient) of i^{th} surface of the wall; A_c – albedo of the underlying surface (table 3.4); N – the number of the wall surfaces, from which the reflected radiation gets on the given surface.

Table 3.4 Coefficient of the radiation reflection-A from different underlying surfaces and materials

Material	A	Underlying surface	A
		Brick:	
		red	0,32
Snow:	0,85	white	0,65
Fresh	0,65	Limestone:	
Stale	0,3	light	0,65
Light sand	0,2	dark	0,5
Bare earth	0,8	Sandstone:	
		light	0,4
Water	0,05	dark	0,25
		Asphalt	0,18
		Light concrete	0,3

The quantity of the reflected radiation to the surface a_1d_1 (see picture 3.4) may be calculated by formula (3.14). In case if that the underlying surface is concrete (A=0.3), so from 8 to 9 in the morning (direct radiation on the horizontal surface I_{dr}=509 W\m^2, diffused radiation $I_{dif.}$=119 W\m^2) and for φ_{w-c}=0,5:

$I_{ref}^{w} = (509 + 119)0{,}3 \cdot 0{,}5 = 94\ vt/m^2$ i.e., the reflected radiation exceeds the diffused radiation (59.5 W\m^2).

The calculations of the reflected solar radiation flow for the areas of surface having different remotes from facade of the building a_1d_1 for 40° n.l. from 8 to 9 in the morning in July by the formula (3.13) are given below.

Distances from facade, m 1 2 5 10 20 100

φ_{c-w} 0,44 0,4 0,258 0,138 0,016 0

Reflected radiation

flow,I_{dif} W/m^2 .... 159 145 93 50 6 0

If to take that the material of the surface of the wall is light limestone (A=0.65), according to table 3.3 the flow of the direct radiation I_{dr} =403 Wt\m^2, then the total flow of the solar radiation coming to the surface of the walls a_1d_1 $I^{\Sigma} = I_d + I_{dif} + I_{ref}$=403+59.5+94=556.5 W\m^2. This flow is the source of the radiation reflected on the earth surface near the façade a_1d_1.

Comparison of this value with the data provided above shows that the reflected radiation exceeds the diffuse radiation noticeably near the wall surface (up to 5 meter).

The heat exchange of long-wavelength thermal radiation between two surfaces may be calculated upon the formula for the radiant heat exchange.

$$Q_{r_{1-2}} = C_r \varphi_{1-2}\left[\frac{T_1}{100^4} - \frac{T_2}{100^4}\right] \qquad (3.15)$$

where C_r – the reduced coefficient of thermal radiation, $C_r = C_0\ X\varepsilon_1\varepsilon_2$; C_0 – constant Stephen-Bolsman, C_0=5,67 W/(m^2 · K^4); ε_1 and ε_2-the emissivity? (the degree of darkness) of the irradiated surfaces; T_1 and T_2 – absolute values of temperature of the irradiated surfaces, K.

In order to calculate of thermal radiation, the temperature of each surface in the construction area can be evaluated for summer regime by the following formula:

$$t_{sur} = \frac{I^{\Sigma}(1 - A_{sur})}{a} + t_a \qquad (3.16)$$

where t_a-the air temperature, °C; α-heat exchange coefficient on the surface W\(m^2 · °C).

4. THE TEMPERATURE REGIME OF THE CONSTRUCTION AREA

The temperature regime means totality of temperature parameters (air temperature, ground surface, surface of the building) of the aggregated under the influence of the climatic conditions characteristic for the given region. It is necessary to state that air temperature and the temperature of surrounding surfaces are the main parameters determining the comfort condition of buildings [7,8] .

The difference between the air temperatures in the construction area and open space is determined by the character of weather and also the temperature, radiation and wind regimes. Temperature variation under the influence of the construction is not great in winter period and doesn't exceed 1,5° C. In the northern regions, improvement of the building microclimate through increasing temperature doesn't give tangible results.

In the southern regions, the inflow of additional heat irradiance from the surfaces heated by the sun and due to the reflected radiation serves as the overheating source. Purposeful influence on the temperature regime is implemented through changing absorption of radiation, the value of albedo of the surface (coverage, paint) and the wind regime of the territory while changing the construction layout.

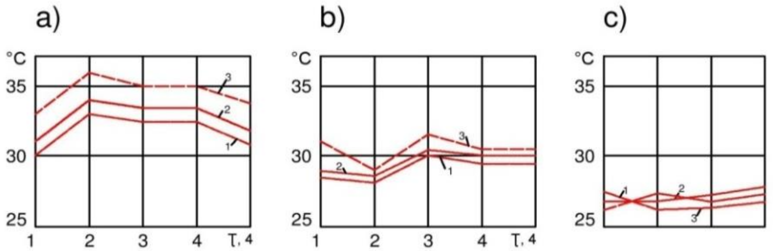
The temperature conditions of the lower layers of air (troposphere) in the building territory are essential in view of providing people with comfortable life conditions. Special conditions are created in this layer under the influence of the solar radiation depending on the character of the underlying surface (soil, asphalt, concrete, lawn and so on). This condition are gradually smoothed to the temperature fixed at weather station depending on the remoteness from the surface and at the level of 200 cm are not emerged practically.

The insolated walls of the building also influence the temperature regime of certain zones which dimensions are more than 10-20 m^2. The quantity of the heat passing to air during the process of convective heat exchange of the insolated walls and air is determined by the difference of the temperature of the incident flow and the surface of walls, the speed of flow near the wall surface as well as the configuration of the building and construction area as a whole.

Some difficulties related to the temperature regime study are observed when considering the equations (1.1) - (1.7) of the building microclimate, as the latter is the complex feature of microclimate and strongly depends on the radiation and wind regimes. It is necessary to solve the whole system of equations of microclimate of the construction territory for precise description of the temperature regime that seems impossible. It is possible only to suggest approximate formulae for calculation of the temperature of the ground surface and the walls of buildings, it is more difficult to estimate the air temperature of the construction territory. Therefore, in – situ measurement is a principal method of study of the building temperature regime. The results of generali zation of in – situ measurements allow to conclude about the temperature regime of the building when the parameters of the wind and radiations regimes are available.

At the same time, as it was stated above, the possibilities of use of the results of in-situ researches at the designing stage are limited. Therefore, the attempt to model the building temperature regime not as a whole, but on its individual parts is of great importance. Like in modeling of any physical pro cess, the theory of similarity is the basis of modeling.

Pic. 4.1 The change of the temperature of underlying surfaces irradiated by the sun and the air of surrounding territory



a–bare ground, b–grass, c–asphalt; 1–full radiation, 2–direct; 3–diffused

Because of the complex character of the temperature regime and its dependence on wind and radiation regimes, the similarity criteria of Reynolds and Grasgof being essential for the wind regime are also determinative for temperature regime. It is necessary to bring the energy equation (1.5) describing the temperature regime to dimensionless form for obtaining other determining criteria:

$$\frac{\partial V_x}{\partial T} + V_x \frac{\partial V_x}{\partial x} + V_y \frac{\partial V_x}{\partial y} + V_Z \frac{\partial V_x}{\partial z} = a\Delta t \tag{4.1}$$

Let's choose the scales of physical parameters: the scale of length L (some typical size of the building); time scale L^2\v; speed scale v\L; temperature scale (t_0-t∞) where t_0-some characteristic temperature in the construction area for example, temperature of the underlying surface.

Let's designate dimensionless sizes:

$$T' = \frac{T}{L}\,v;\, x' = \frac{x}{L};\; y' = \frac{y}{L};\; z' = \frac{z}{L};\; t' = \frac{t_0 - t}{t_0 - t_\infty} \qquad (4.2)$$

After replacement in equation (4.1) and reduction for v (t_0 - t∞) \ L we obtain:

$$\frac{\partial t'}{\partial T'} + V'_x \frac{\partial t'}{\partial x'} + V'_y \frac{\partial t'}{\partial y'} + V'_z \frac{\partial t'}{\partial z'} = \frac{a}{v}\Delta t = \frac{1}{Pr}\Delta t \qquad (4.3)$$

The dimensionless complex included in equation (4.3) Pr=v\a-Prandatle number. This complex is made of physical characteristics of the environment (viscosity and heat conductivity) and, therefore, it is the physical characteristic of the environment. The physical meaning of Prandatle number is determined as the measure of similarity of the fields of speed and temperature in the mobile environment (under Pr=1 and absence of lifting powers the equations of the fields of speed and temperature coincide, i.e., the fields are similar).

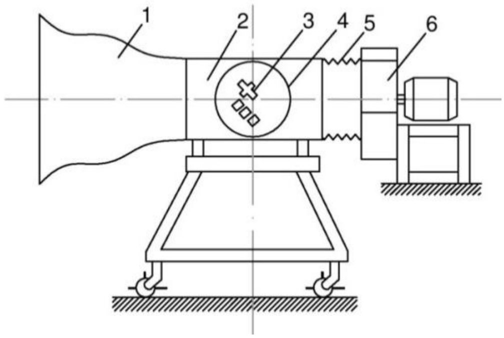
In such a way, equality of criteria Reynolds, Grasgof and Prandatle is the enough condition of similarity during modeling of the temperature regime of the building. The difficulties regarding the modeling upon Reynolds number have already been stated in Section 2. But like in modeling of the winter regime, it can be mentioned that as the field of temperature where the distance from the surface of the building significantly exceeding the thickness both of thermal and hydro-dynamical marginal layer is researched, the process may be considered as auto-models with respect to the Reynolds criterion.

It is necessary to distinguish the cases of big and small speeds of the incidental wind flow according to Grasgof number during modeling. The inertial powers are more than lifting power in higher speeds conditioned by variation of density of heating and cooling masses. In equation (1.3) the members characterized by the lifting powers may be neglected. Then, the Grasgof criterion falls out from numbers determining the criteria and modeling upon it is not obligatory.

In lower speeds of the incidental flows conditioned by inequality of the temperature field become the main reason and in zero speeds of the external flows-the sole reason of the convective movement and the Grasgof criterion becomes essentially determinative. However, modeling according to Grasgov number is related with very great difficulties. The linear size enters to the third decree in the expression for determining the Grasgof criterion Gr=gβ (t_0-t∞) L^2/ v^2, therefore, it is not possible to implement the equality condition of the Grasgof criterion in the model and in-situ. But analogical to modeling upon Reynolds number positive value has auto-modeling of the process. In the wider range, the changes determining the parameters of the temperature field are auto-model in connection with the Grasgof criterion, i.e., in implementation of equality of other determining criteria the temperature fields of the model and natural object are similar.

It was already noted that Prandatle number is the physical character of the mobile environment, and for air this characteristic is weakly dependent on temperature. Therefore, if modeling of the temperature regime is implemented in the same environment as in situ, then the equality of the Prandatle criteria is implemented automatically.

Pic. 4.2 A scheme of experimental installation for the research of the building temperature regime



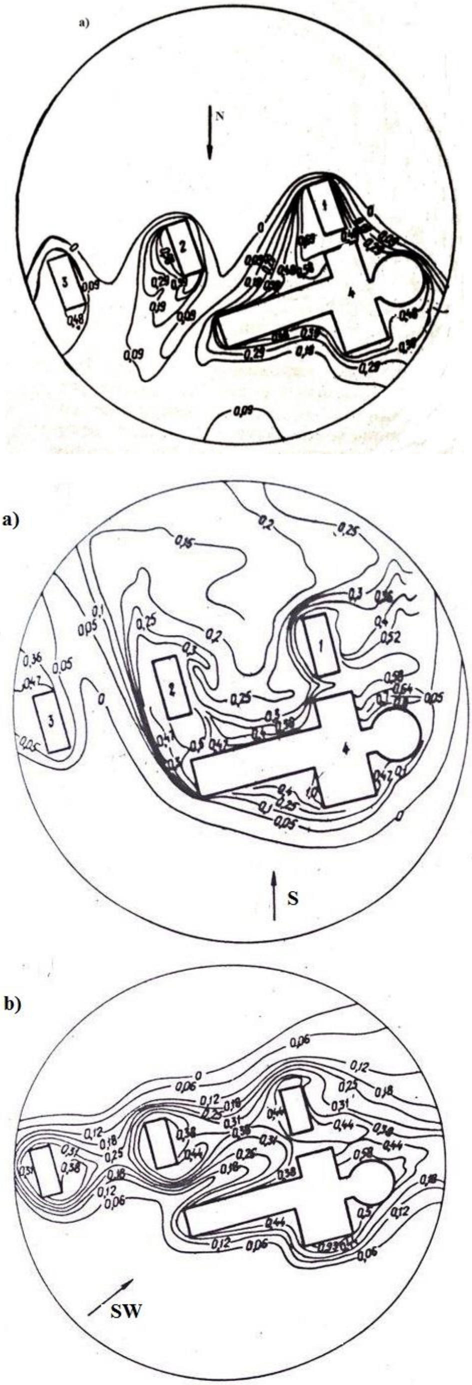
1. Vitoshinky nozzle; 2. Working part of the aerodynamic pipe; 3. Model of the building; 4.Window for connection of interferometer; 5.Elastic insert; 6. Ventilator.

Research of the temperature regime of the air environment between the buildings at hours of influence of the solar radiation was implemented in the model of resort complex (picture 4.2) erected in the region of the Absheron peninsula of Azerbaijan. The task of the research was to reveal the influence of heated surfaces of the wall of the building on temperature variation in the air flow washed by them.

The model of the resort complex was made of wood in scale 1:500. Nichrome foil stripes with 0,2 mm thickness were glued on the surfaces of the models imitating the walls of the building. The stripes with big total resistance against current were glued on the surface turned to the solar side. Therefore, these surfaces had higher temperature during the experiment while passing the latter.

The model of the resort complex was installed in the aerodynamic pipe and was blown by air flow. The centrifugal fan designed for developing dynamic pressure was connected to the aerodynamic pipe through the intermediate elastic fitting preserving the pipe and model inside which was installed against vibration conditioned by work of the fan and engine.

Pic. 4.3 Isotherms of the temperature field of real version of the building

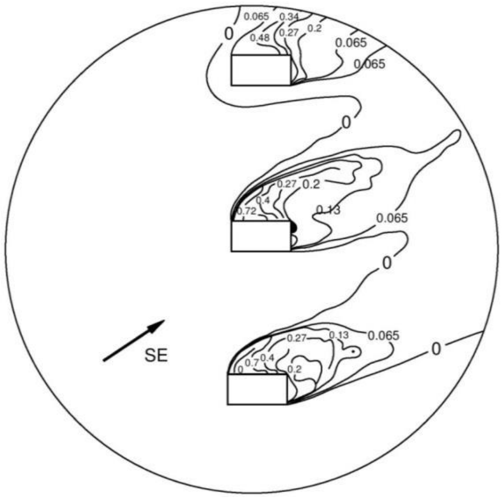


a - Northern direction of the flow; b. – ditto, southern; c – ditto, south – western

The research of the temperature field of the air environment is realized via the interferometer. Round windows protected by optic glasses were pro vided in the working part for this purpose. Butts of the models of the buildings were squeezed between the glasses. The windows established the working field for research via interferometer installation. The interferential pictures were photographed during experiments and the pictures obtained via interferogram were decoded using famous method.

The speed of the incidental flow of air equal to 3 m\s measures using semiconductor thermo-anemometer. Next conditional directions of air flow were considered: northern, northwestern, southern, southwestern and south eastern. Selection of directions is conditioned by dominating directions of wind in the Absheron peninsula. While directing experimental researches, it was supposed that enclosure of southern and western orientations had higher temperature at hours of intensive influence of solar radiation. Therefore, the temperature on the surface of the external enclosures of these orientations was higher than on the surface of other orientations during experimental re searches. Two versions of building have been considered: conditional version – "lower - case" building and real version of the building. The isotherms of dimensionless temperature field corresponding to different versions of the building and the character of its flow were built according to the results of processing by interferogram (pictures 4.3and 4.4).

Pic. 4.4 Isotherm of temperature field of the conditional version of the building



Dimensionless temperatures relating to different isotherms were calculated according to the following formula:

$$\theta = (t^{M} - t^{M}_{H})/(t^{M}_{w} - t^{M}_{H}) \quad (4.4)$$

Where t^{m}-the value of temperature in the given point of the temperature field of the model, determination during processing by interferogram, °C, t_{H}^{M} – temperature of incidental flow during modeling, °C, t_{w}^{M} – temperature of the surface of the model of the building, °C.

The scheme with isotherms of the dimensionless temperature field (see picture 4.3, 4.4) can be considered as the maps of the temperature regime of the buildings analogical to the maps of wind and radiation regimes considered above.

According to the size θ taken from the map, the temperature in some points of the real building may be calculated by the following formula:

$$t = t_{H} + \theta(t_{w} - t_{H}) \quad (4.5)$$

where t_{H}–the temperature of incidental flow in the real building area, °C (temperature outside the building), t_{w}-temperature of the surface of the wall of the building, °C.

The temperature of the outside surface of the walls at hours of intensive influence of solar radiation may be calculated using the following formula:

$$t_{w} = 0{,}9 \left\{\left[A_{t_{H}} + \frac{\rho(I_{max} - I_{w})}{\alpha_{H}}\right]\frac{\alpha_{H}}{\alpha_{H}+s} + t^{w}_{H} + \frac{\rho I_{w}}{\alpha_{H}} - \frac{k}{\alpha_{H}}\left(t^{w}_{H} + \frac{\rho I_{w}}{\alpha_{H}} - t_{a}\right)\right\} \quad (4.6)$$

where t^{w}_{H}, A_{tH}-average daily values and amplitude of temperature variations of the outside air, °C, I_{max}, I_{w}-maximum and average daily values of intensity of total solar radiation on the vertical surface of corresponding orientation, W/m^{2}; Q-coefficient of absorption of total solar radiation flow of the external surface of the walls; a_{H}– coefficient of thermal exchange on external surface of the building, W\(m^{2} · °C); t_{B}– indoor air temperature, °C; k – coefficient of heat transfer of the enclosure, W\(m^{2} · °C); s- coefficient of heat absorption of the material of the external surface of the enclosure, W\(m^{2} · °C);

Formula (4.6) was obtained on the basis of exact solution of the problem on passage of average daily thermal flow through the enclosure and approximate solution of the problem on attenuation of the outside thermal influences while passing through outside surface of the enclosure. Let's estimate the temperature of external walls of the building of the resort complex using it at hours of intensive influence of the solar radiation. Basic information: I_{max} = 740 W/m^{2}; $I_{av.}$-163W/m^{2} for the walls of the western orientation; t^{w}_{H} = 26 °C; A_{tH} = 8 °C, p = 0.8; t_{H} = 26 °C, α_{H} = 23 W\(m^{2} · °C); k = 1.4 Wt\(m^{2} · °C); s = 7 W\(m^{2} · °C).

Putting the basic data in formula (4.6), we obtain the value of the temperature on the surface of the walls of the building of the eastern orientation t_w=43.8°C. The formula (4.5) will be as following for calculation of the temperature field:

$$t = t_H + \theta(43{,}8 - t_H) \qquad (4.7)$$

If to accept that for Absheron peninsula t_H = 30 °C at hours of intensive influence of the solar radiation, then we will obtain:

$$t = 30^0 + 13{,}8\,\theta \qquad (4.8)$$

The calculation of the temperature field between the buildings of the construction territory may be implemented according to formula (4.8).

The analysis of the temperature field of the resort complex leads to the conclusion which may be used during general estimation of the microclimate of the building:

- *Air temperature on the leeward part at average is higher than the temperature in the incidental flow by 4 °C in southern part of the wind and by 3.6 °C in the southwestern part of the wind for real version of the building;*
- *Air temperature near the dwelling bodies in the northern direction of wind in the windward side is equal to the air temperature of the incidental flow, but higher than the air temperature in the leeward side by 4 – 7 °C.*
- *The highest air temperature is observed in the northern direction of the wind in the region of residential building N 1 and domestic building N 4 (see picture 4.3 a).*

Temperature in the air flow behind the building is aligned and becomes equal to the air temperature in the incidental flow at the distance of one height of the building.

5. METHODS OF COMPLEX ASSESSMENT OF THE MICROCLIMATE OF BUILT UP TERRITORY

Special microclimatic conditions (temperature, air motion speed, humidity and so on) which are formed in the surface air around the buildings and faci lities are understood under microclimate of the built-up territory. It is conditioned by variations of the wind regime in the building with the features of distribution of entrances of the solar radiation (direct, diffuse and reflected) and radiant heat exchange between different surfaces of the building [9-11].

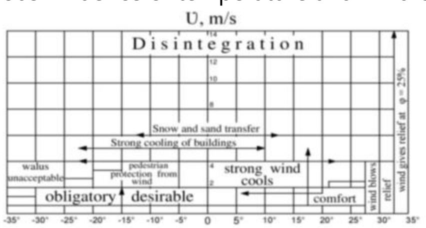
It is necessary to take into account the meteorological factors and design solutions while developing the method of estimation of the conditions of the microclimate of the built-up territory, wherein it is necessary to base on heat sensation of people. The most important matter in this case is selection of criterion of the microclimatic conditions optimality which shall be the feature of comfort conditions for people dwelling in the building territory. The characteristic of each climate differ and accordingly the comfort requirements vary from one climatic zone to another. Before proceeding further, in would be useful to define comfort and the conditions that affect it. According to American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) definition [12], thermal comfort is , “that condition of mind which expresses satisfaction with the thermal environment”. It is also, “the range of climatic conditions within which a majority of people would not feel discomfort either of heat or cold”. Such a zone in still air corresponds to a range of 20-30°C dry bulb temperature with 30-60% relative humidity.

Comfort condition of people is determined by heat sensation which in its turn depends on heat and mass exchange of the body of man. Heat and mass exchange of the body depends on whole range of factors: temperature and relative air humidity, speed of air flow, feature of the radiant heat exchange of body of people with environment (outside radiation flows, temperature of surrounding surface and etc.), heat production of the organism, heat isolation capacities of clothes and so on. Description of constituent heat exchange of the body of people with surrounding environment of the premises gives following data [13]: radiation heat exchange with surrounding surface – 42%, convective heat exchange with ambient air; 26%, heat exchange due to evaporation from the surface of the skin-18%, heat exchange due to the heating of air while breathing-7%, heat exchange due to evaporation from the surface of lungs while breathing-7%. If a person is out of doors, it is necessary to add here components related with heat input conditioned by the solar radiation.

The values of different characters of the microclimate of the building allow to give some estimation from the point of view of comfort conditions for people in the building territory. Thus, the upper bound of the comfort speed of wind for pedestrians determined by hygienists is 3.5 m\sec. Optimal speed in cool and warmer weather is 1 – 2 m/sec. The permissible wind speed is 5 m\sec, the higher wind speed cause discomfort. In cold weather such speed causes strong cooling of people and buildings, and therefore protection of pedestrians against wind at the speed up to 4 m/sec is necessary. In warm and hot weather, the wind speed to 4 m/sec is considered as a positive factor, as it decreases overheating level, but in hot dry weather it can be harmful (dries up the skin, carries dust and sand). Under certain types of weather, wind in combination with air temperature may be considered as a negative factor (In cold, cool, hot weather) and as a positive factor (warm weather). A diagram is proposed for evaluation of the microclimate of the territory under joint influence of the temperature and wind loads (picture 5.1) [14].

According to the diagram, the wind with a speed higher than 4 m/sec is not favorable for pedestrians at any weather, it only irritates them. The speed more than 6 m/sec is characterized by transfer of snow and sand. At wind speeds 12 m/sec and more, separate light elements of the buildings may be broken, and at zero temperature and in relative air humidity of 70% and more any wind is unfavorable for people. At the temperatures below zero and speeds more than 4 m/sec protection of pedestrians against wind is desirable, the speed more than 5 m\sec conditions protection of buildings, because too much heat is lost due to infiltration. The wind speed up to 2.5 m / sec at the temperature 20-28 ºC is favorable. Under 28-33 ºC temperature conditions and 1-4 m/sec wind speed aeration of the premises is necessary. At the tem perature more than 33º C, especially during transfer of the sand, dust and decreased relative air humidity (less than 25%), the wind nearly doesn’t give facilitation and can easily cause irritation. Therefore, implementation of closed and semi-closed construction types is recommended in the deserts.

Pic. 5.1 Diagram for the assessment of the microclimate of territory under simultaneous influence of temperature and wind conditions



For example, effective temperature is determined as the temperature of saturated air causing the same heat sensation like as unsaturated air under the researched temperature. This complex character depends on temperature and humidity of outside air and speed of air flow. The diagram for determination of effective temperature on the basis of the known parameters of the medium is stated in [13]. The relation between the scale of effective temperature and heat sensation of people is described in table 5.1.

A whole range of practically useful recommendations regarding the effi ciency of different design solutions of the building derived from early researches is related with such characters as evaluation of microclimate of the territory and effective temperature. Particularly, the data on the influence of some urban planning methods on the change of temperature efficiency for the desert zone of Central Asia are given in work [15].These results are given in table 5.2.

There are wide distributions called as bioclimatic diagrams for bioclimatic estimations in the foreign practice (picture 5.2) where the results of hygienic experimental researches are used during their construction [16].

The diagrams are drawn up in the coordinates of the temperature of the outside air – relevant humidity. The curves corresponding to different points of dew are shown in the diagram. There is the comfort zone corresponding to the relevant humidity within 30-60% and the air temperature nearly 24ºC when the condition of warm comfort is felt in calm position in light summer dress (nearly 1 klo) in the central part of the diagram. The decrease of air tem perature is necessary during additional radiation for keeping the comfort condition, meanwhile, nearly 7W\m^2 compensates the decrease of temperature to 1ºC. This effect is felt for example, in the mountains where the people don't freeze in the Sun. The wind makes cooling effect under lower humidity, therefore, the boundary of unpleasant feeling moves in the field of higher absolute humidity. It is fair during moderate speed of air motion. In higher wind speed discomfort feeling appears. **Diagram 5.1.**

Diagram 5.1: wind protection of outdoor spaces in discomfort (cold and hot hours) limits

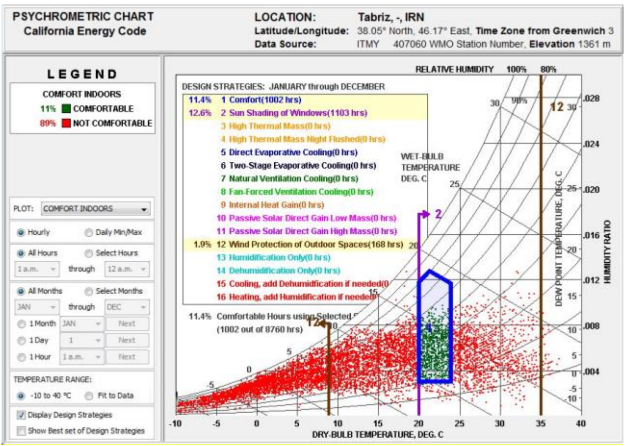


Table 5.1. Dependence of the human's thermal state on the effective temperature

Effective temperature value, ° C	Heat feeling	Reaction of organism
42 – 40	Very heat	Strengthened sweating and blood circulation. Blood supply disturbance of cardiac vessels (danger of thermal shock)
35	Hot	Intensive sweating and blood circulation
		Normal thermoregulation by diaphoresis
30	Warm	Regulation of muscular blood circulation
25	Comfort	Strengthening of visible heat emission and heat regulation using clothes
20	Cool	Constriction of blood vessels of feet and hands. Dryness of mucous membrane of the oral cavity and skin
-10	Cold	Pains in muscles, disturbance in peripheral blood circulation
-15	Very cold	

Table 5.2 Variation of effective temperature during the use of different town building applications

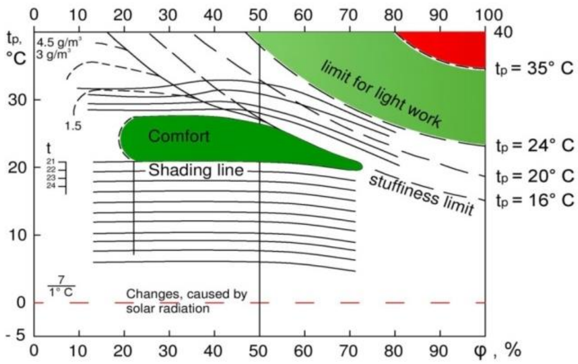
Town building application	Effective temperature for microclimate softening, ° C
Application of artificial shaded devices	up to 3,1
Closed squares, pavements, paths made of porous materials with low heating capacity with their watering	0,8 – 0,9
Laying pedestrian roads at the distance of 1 – 1.5 height from the building (depending on its orientation).	0,5 – 0,7
Planning of buildings contributing to ventilation of the territory with ruptures not less than 2 heights depending on its orientation).	0,3 – 0,9
Protection of buildings from the insolation of climbers depending on its orientation).	0,6 – 1,1
Establishment of small yards of the size not more than 4 – 5 height protected against hot winds;	0,2 – 0,4
Placement of yards taking into account prevailed directions of wind at night	1,2– 1,5
Creation of compact masses of landscapes of the square 15 – 20 ha	4,6 – 4,7
Water pools of the square 100 - 150 m^2	2,1
Watering of the territory	1,7

At this case we can reduce negative effect of wind blowing in hot or cold conditions by using architectural or landscaping manners as shown in schema 5.1.

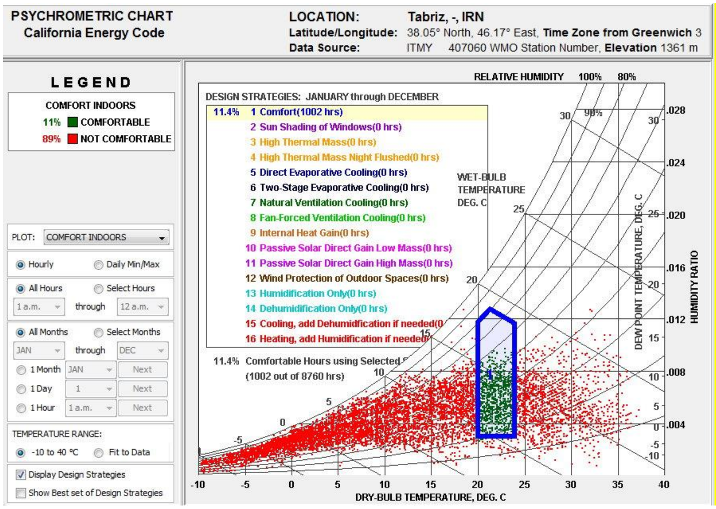
The Pic. 5.2 shows the field of stuffiness where the evaporation is decreased and overheating of organism may happen. The temperature of the dew point -24° C states the boundary of comfort during easy work even for trained person. At the dew point of 35° C heat release is stopped and the danger of thermal shock occurs if the body is undergone to further heating. Such case can occur even in the shade under the humid greenhouse condition or on the bank of the pool under intensive solar radiation. Comfort conditions may be created during evaporation of water from pools and spraying of water from fountains, as well as during evaporation from the leaves of plants in dry and hot weather.

The scales in the left part of the diagram show that the boundary of the comfort zone can be moved down (or upwards) if the average radiation temperature of the surrounding surfaces differs from the air temperature. The difference 0,8ºC of average radiation temperature is compensated nearly 1ºC from air temperature. The samples of use of bioclimatic diagrams to study the microclimate of the built-up territory are given in the former publications [17].

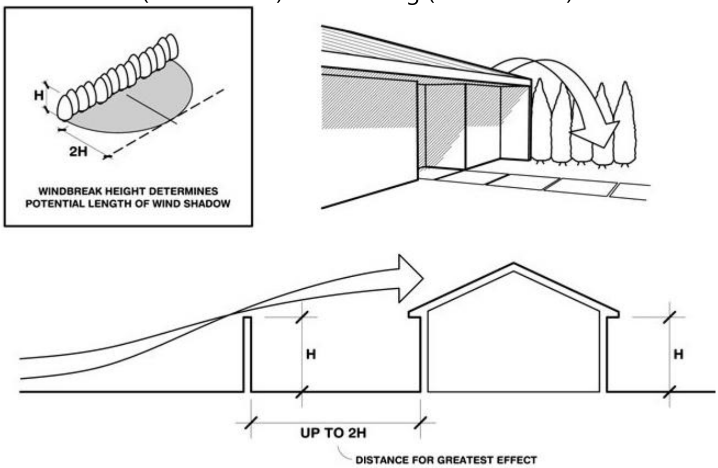
Pic. 5.2 Bioclimatic diagram of Olgyay



Picture 5.3: Comfort zone in our studied region (CLIMATE CONSULTANT program result)



Schema 5.1: Architectural or landscaping way for wind protection (cold climate) and shading (Hot climates)



It is necessary to state that all the mentioned methods of assessment of the microclimate of the territory are limited in known degree. First of all, it is related to the fact that no one method doesn't consider completely all complexes of the microclimatic factors of the external environment influencing the thermal condition of people and the parameters of the building forming this complex. Besides, as a rule, these methods are based on subjective assess ments of thermal feeling of people.

The main criterion allowing to judge the comfort degree of the meteorological conditions is the skin temperature, as the latter objectively expresses the reaction of organism against the impact of microclimatic factors and serves as one of the indicators of people's thermal condition.

The analytical dependence between average skin temperature and para meters of the external climatic conditions may be obtained on the basis of examination of the equation of human body's thermal balance, utilization of which leads to a range of advantages compared to other methods: the subjectivity element is absent in the evaluation, the equation consist of a comp lete complex of meteorological factors, the character of activity of person and heat-resistance role of clothes are taken into account. The methods of the microclimate assessment on the basis of the equation of thermal balance of human body got the name of biometeorological methods. A whole range of work of the local and foreign researchers is devoted to it.

Especially high convergence of the results of the bioclimatic assessment of microclimate through people's thermal sensation is observed during positive air temperatures under hot climate conditions.

Table 5.3 Dependence of the human's heat feeling on the skin temperature

Heat feeling	Skin temperature, ^{0}C
Very hot	35,6-36,5
Warm	34,4-35,5
Heat	33,4-34,3
Comfort	32,2-33,2
Cool	30,0-32,1
Very cold	28,1-29,9

The equation of thermal balance per 1 m^2 of the body surface can be written in the following form:

$$\mathrm{M} - q_b - q_s = q_c = \pm q_r + q_c \qquad (5.1)$$

where M-body heat production per unit of body surface, W\m^2; q_b – heat exchange of a man conditioned by breathing, W\m^2; q_s - heat emission of body, due to the thermoregulation processes of sweating, evaporation of moisture and diffusion of water steam through the skin, W\m^2; q_0-heat emission from the skin surface to the clothes (heat emission through clothes), W\m^2; q_r – radioactive thermal flow on the external surface of the clothes, W\m^2; q_c – convective heat emission from the external surface of the clothes, W\m^2.

The heat production of organism (metabolic heat) is associated with the consumption of oxygen by the organism necessary for normal proceeding of the internal processes and depends on the kind of activities (table 5.3).

Table 5.4 Heat production of organism during different kinds of human activities

Condition or kind of human activity	Heat production per the unit of the body surface, W/m^2
At rest: lying sitting standing	 50 60 70
Walking on a flat road with the speed from 3.2 to 8 km/hour	115-340
Sports activities: gymnastics tennis badminton basketball	 170-230 270 420 440
Labor activities (conditional distribution depending on heaviness of work) minor easy moderate heavy	 to 95 95-115 115-200 more 200

Heat loss of man conditioned by breathing composes of two parts:

$$q_b = q_{b.f} + q_{b.c} \tag{5.2}$$

Closed heat emission while breathing $q_{b.f,}$ W/m^2 is conditioned by variation of absolute humidity of the breathed air.

$$q_{b.f} = 0{,}0027M(44 - p_a) \tag{5.3}$$

Where p_a-the partial pressure of water vapors in the breathed air, mm. mr. cl.

The visible heat emission during breathing ($q_{b.f,}$ W/m^2) occurs as a result of heating of the breathed air in the lungs. The quantity of heat lost by body during this process may be determined on the formula:

$$q_{b.c} = 0{,}0014M(34 - t_a) \tag{5.4}$$

where t_a – the temperature of ambient air.

Heat return of body as a result of sweating, moisture evaporation and diffusion of vapor through the skin is determined by the following formula:

$$q_s = q_{s.b} + q_{b.b} \tag{5.5}$$

where $q_{s.b}$ - the heat emission due to the diffusion of water vapor through the skin, Wt/m^2.

$$q_{s.b} = 0{,}41\ (\ 1{,}92\ t_s - 25{,}3 - p_a\ )\ (5.6)$$

where t_s– the temperature of the skin, ° C; p_a - the partial pressure of water vapors in the breathing air, mm.mr.cl.; $q_{s.b}$-the heat return due to the diffusion of water vapor through the skin, W/m^2, determined according to formula from [17]:

$$q_{b.b} = 0{,}42\ (\ M - 50\ ) \tag{5.7}$$

As it is seen from (5.7), at comfort rest condition (M = 50 Wt/m^2) sweating doesn't occur.

Heat emission through the cloths, Wt /m^2 is determined by the known formula:

$$q_c = \frac{t_s - t_c}{0{,}155} k_c \tag{5.8}$$

where t_c-the temperature of the external surface of cloths, °C; k_c-the indicator of thermal isolation capacity of clothes, klo.

The unit klo is accepted in the hygienic practice: 1 klo =0.155 m^2 · K/Wt. Following values of indices of heat isolating capacities are correspondent to different types of clothes: without clothes – $k_{cl.}$ = 0 klo, light summer cloth - 0.5 klo; usual summer clothes in the moderate length-1 klo; cloth of transiti onal seasons – 2klo; warm winter cloth – 3 -4 klo.

Convective heat emission, W/m^2 from the body surface of the dressed person is calculated using the following formula:

$$q_k = a_H(t_c - t_a) \tag{5.9}$$

where a_H – the coefficient of convective heat exchange between clothes and ambient air, W/(m^2 · °C)

$$a_H = 1{,}16\ (\ 5 + 10\sqrt{v}\ ) \tag{5.10}$$

The radiation thermal flow on the surface of clothes including some com ponents is calculated difficultly enough.

$$q_r = q_{r.f} + q_{r.s} + q_{r.c} + q_{r.r} \tag{5.11}$$

where $q_{r.f}$ is the radiation flow from direct solar radiation W/m^2.

$$q_{r.f} = \frac{1}{\pi} I_h^{dr} ctgh \tag{5.12}$$

where $I^{dr}{}_h$-the flow of direct solar radiation on the horizontal surface, W/m^2; h – height of the Sun, grad.

When deducting (5.12) it is conditionally accepted that the human body is the vertical cylinder having the height of H and radius of R. The irradiation flow $I^{dr}{}_h$ctg h fallen on the cylinder surface perpendicularly to its axis is determined by the following formula:

$$Q = 2H \int_0^{\pi/2} I_h^{dr} ctgh\ \sin\alpha\ Rda = 2HR\, I_h^{dr}\ ctgh$$

Dividing the size Q into the square of the surface of the conditional body we obtain the required size:

$$q_{r.f} = \frac{Q}{2\pi} RH = 2HRI_h^{dr} \frac{ctgh}{2\pi RH} = I_h^{dr}\ ctgh/\pi$$

The radiation flow entered to the surface of cloths from diffused solar radiation , is equal to :

$q_{r.c} = I_r k_{irr}(\ 1 - A_C\ )$ (5.13)

where I_r-the flow of the diffused solar radiation, W/m^2, $k_{ir.}$ -is the coefficient of irradiance of the human body by the firmament determined by formulas (3.8) - (3.11), A_c – albedo of clothes admitted equal to 0.3.

The flow of the radiation reflected from the surface of the external walls of the building and the ground surface, W/m^2 is:

$$q_{r.ref} = (\ \textstyle\sum_{i=1}^{N} I_{w.i}^{\Sigma}\ A_i \varphi_{h-i} + 0{,}5 I_t^{\Sigma} A_t)\ (\ 1 - A_c) \tag{5.14}$$

where $I^{\Sigma}_{w.i}$-the density of the flow of summary solar radiation on the i^{th} surface of the walls of the building surrounding the people, W/m^2 (determined by the method stated in section 3); A_i-albedo of the i^{th} surface of the building; I^{Σ}_{t} – the density of the total solar radiation flow on the ground surface, W/m^2 (determined by the method stated in section 3); A_t-albedo of the underlying sur face; φ_{h-i}-coefficient of irradiation between the i^{th} surface of the wall and human body; A_c –the radiation flow due to the radiant heat exchange between the surrounding surfaces of the buildings and human body, W/m^2.

The radiation flow on the account of the radiant heat exchange between the surrounding surfaces of the building and human body, W/m^2:

$$q_{r.r} = \sum_{i=1}^{N} C_{b.i}\,\varphi_{h-1}\left[(\tfrac{t_i+273}{100})^4 - (\tfrac{t_c+273}{100})^4\right] + 0{,}5C_{b.t}\left[(\tfrac{t_t+273}{100})^4 - (\tfrac{t_c+273}{100})^4\right] \quad (5.15)$$

where $C_{b.i}$ – the reduced factor of the thermal radiation.

$$C_{b.i} = C_0\varepsilon_i\varepsilon_c \quad (5.16)$$

C_0=5,67-the coefficient of blackbody radiation, W/(m^2·K^4); ε_i-the degree of blackness of the i^{th} surface of the wall; $\varepsilon_c \approx 0.9$-the degree of blackness of the external surface of clothes; $C_{b.t}$ – reduced factor of the thermal radiation.

$$C_{b.t} = C_0\varepsilon_i\varepsilon_c \quad (5.17)$$

where ε_i – the degree of blackness of the underlying ground surface; t_i – the temperature of the i^{th} surface of the wall, °C;t_c-is the surface of the underlying surface, °C;

While calculating the radiation factor between the surfaces of the walls of the building in the construction and human body, it is rational to use approximate method when a man is considered as a point at a height of 1,5 meter from the ground surface with respect to the building and the surrounding walls of the building are approximated by rectangle planes with different sizes within the limits corresponding solid angles. In this case, calculation of the irradiance coefficients doesn't cause difficulties.

Putting expressions (5.2) – (5.17) in initial equation (5.1) we obtain the system of two equations giving the description of heat condition of people under the conditions of the built – up territory:

$$M[1 - 0{,}0027(44 - p_a) - 0{,}0014\,(34 - t_a) - 0{,}41\,(1{,}92\,t_k - 25{,}3 - p_a) - 42(M - 50) - 1{,}16(5 + \sqrt{v})(t_c - t_a) + \frac{1}{\pi}I_h^{sr}\,\mathrm{ctg}\,h\,(1 - A_c) + \sum_{i=1}^{N} C_{b.i}\,\varphi_{h-1}\left[(\tfrac{t_i+273}{100})^4 - (\tfrac{t_c+273}{100})^4\right] + 0{,}5C_{b.t}\left[(\tfrac{t_t+273}{100})^4 - (\tfrac{t_c+273}{100})^4\right] = 0 \quad (5.18)$$

$$M[1 - 0{,}0027(44 - p_a) - 0{,}0014\,(34 - t_a) - 0{,}41\,(1{,}92\,t_k - 25{,}3 - p_a) - 0{,}42(M - 50) = \frac{t_k - t_c}{0{,}155k_c} \quad (5.19)$$

Equation (5.19) is necessary for determination of the unknown previously temperature of clothes of people, t_c.

Equations (5.18) and (5.19) include some groups of parameters characterizing the comfort of people in the built – up territory:

parameters associated with physiological reactions of organism – M, t_k.

parameters characterizing clothes – k_c, A_c, ε_c, t_c.

parameters of the wind regime of the territory – V;

parameters of the radiation regime of the territory - I^{Σ}_t, I^{Σ}_{wi}, A_t, A_i, ε_3, ε_i, h.

parameters of the temperature regime of the territory
t_a, t_i, t_t, p_a; geometric parameters of the territory – φ_{h-i}

Equation (5.14) allows to determine the value of an average temperature of human skin which may serve as the evaluation of people comfort in the building territory while using the data characterizing microclimate of the building.

Basing on the results of multiple studies, Fanger [8] suggested to bind the value of the skin temperature meeting comfortable heat sensation with heat production of the organism which in its turn depends on the kinds of human activities (table 5.3):

$$t_k^{com} = 35 - 0{,}032M \quad (5.20)$$

where t^{com}_k-the skin temperature, °C meeting the comfort heat sensation of people during heat production of organism M.

The method of town building decisions assessment using equations of heat balance of human body is similarly considered in [6]. Initially presetting the skin temperature t_k, the indicators of the microclimate, characteristics of the building surrounding people, kinds of human activities and clothes type using computer method of the successive approximations, the final values of the skin temperature reflecting thermal condition of people in concrete town – building situation are determined. Comparing the obtained value of t with the values of the skin temperature meeting the comfort condition [33.3-34.3°C or according to equation (5.20)], as well as individual components of the heat balance with rated indicators in the zone of thermal comfort, it is possible to assess the microclimatic conditions, and the town-building decision from the point of view of the thermal condition of people.

As this method takes into account geometric parameters of the building meeting concrete architectural-planning solutions and the microclimatic factors conditioned by them, there is a possibility to use this method at the designing stage.

Individual areas and calculation points which may characterize averaged microclimatic conditions in every area are indentified in the construction territory. The equation of heat balance of people is solved for these calculation points. The obtained results allow to estimate the comfort degree of the microclimatic conditions for every area, to precise the architectural – planning solution of the building, to outline the ways of functional use of different areas, the degree of their improvement and landscaping.

The equation of the heat balance of people allows to use widely different private questions for general town building solutions (shading of some areas of the territory, placing the paths for pedestrians, and etc). In this case, a whole range of parameters in equations *(5.19)* and *(5.20)* may be fixed and after setting their values in the equation, it becomes useful for manual calculation. Some samples for solving such kind of tasks are shown in [18].

Fanger suggested to use the equations of the heat balance of human organism for the development of such called comfort diagrams, using the same principle, when a part of parameters is fixed: the types of human activities, cloths and so on are determined [19].

Returning back to the general equation of the heat balance "man-environment", it is possible to state that this equation together with the research results and calculations of the wind, radiation and temperature regime of the building allows to create the model of the forecasted microclimate of the territory, to evaluate it from the point of view of people physiological comfort, to choose on this basis an optimal version of design solution at the design stage. Using this method, it is possible to analyze the microclimatic conditions in the existing building to develop the measures on improving the environment by architectural planning means, as well as investigate the efficiency of architectural planning means in the regulation of the building microclimatic conditions.

6. HYGIENIC ASSESSMENT OF THE THERMAL INDOOR MICROCLIMATE

It is acceptable to describe systematically the heat exchange between human body and environment, as well as its regulation. Let's appeal to the human physiology in order to become familiar with the calculation of the heat sensation parameters and to understand their regularity.

Sweating becomes the decisive factor of heat emission as a result of work of muscles under the increased heat production conditions, since the organism isn't able to get rid of excessive energy through visible heat emission for supporting temperature balance. So, for example, if the oxygen consumption by people increases 5 times in comparison with rest position, then 75% of heat extracted by them is lost through sweating. Moisture emission through sweating may be 2000-3000 ml/hour within small time interval that corresponds to the heat consumption from 1,4 to 2,1 kW/ hour during intensive physical work.

Finally, in connection with the thermoregulation it is necessary to say some words about the lack and excess of heat in the organism associated with the changes of body temperature. The specific heat of human organism is nearly 0,97W·hour/(kg·°C). In other words, if the temperature of the man weighting 70 kg changes by 1 °C, it means the loss or gain of 66 W/ hour heat. As the value of heat production is 88 Wt/hour at rest, it is obvious that the temperature increase or decrease is the main factor of thermoregulation.

The decrease of the body temperature (hypothermia) may happen naturally, if cooling can't be compensated by heat production and artificial ways (due to the use of medicaments) that is practiced in the medicine. The latter case is not considered from the point of view of heat sensation.

The total heat and energy balance of people is described by the following equation:

$$Q_i \pm Q_k \pm Q_l - Q_i - Q_c - Q_p \pm \Delta Q_e = 0 \tag{6.1}$$

where Q_i-the heat production of the organism (total quantity of energy produced by the organism), Q_k,Q_l,Q_i-components of the heat exchange of people through convection, irradiation and on the account of consumption of heat by moisture evaporation, Q_c-heat consumption (energy) for mechanical work; Q_p -heat consumed for the physiological process (heating of the breathed air, natural metabolism and so on), ΔQ_e – excess (accumulation) or lack of heat in the organism.

Total heat production Q_i depends primarily on the severity of the work implemented by people. The heat consumption Q_c usually constitutes 5-35% from additional heat emission related to the implementation of physical and mental work. For example, for moderately severe work implemented in the standing position (Q_i=300 W), this percent is equal to 20. Heat Q_p doesn't exceed 1,6 Wt and it can be ignored during calculations.

If the heat production of organism is not balanced with the heat loss, then the accumulation of ΔQ_e associated with temperature increase or its deficiency leading to overcooling of the organism can be observed. The system of organism thermoregulation allows providing the balance of the produced and lost by body heat within certain limits. However, the possibilities of thermoregulation are very limited.

Variation of the body temperature associated with excess or lack of heat may be considered if the intermediate weight is taken 70 kg and the specific heat of the body is 3,48kJ/kg·°C. In this case the thermal condition of people is not optimal, and the condition in which they are present is discomfortable.

The intensity of heat emission by people depends on heat situation in the premises which is determined by the following indicators: temperature t_B, mobility V_B and relative humidity φ_a of air in the premises, temperatures of the surface circulated in the premises, their placing (relative to people) and the dimensions determining the radiation temperature of the premises t_r. The comfortable combination of these indicators is relevant to such optimal meteorological conditions where the thermal balance is maintained and there is no tension lacks in the thermoregulation process. In the most cases, the comfortable combination of these indicators is positively estimated by the people who are in the premises. The meteorological conditions under which the thermoregulation process tension occurs and a small discomfort in the thermal condition may happen are considered permissible.

There are a lot of empirical formulas prepared by doctors-hygienists for the calculation. The formula for determination of the radiant heat exchange component obtained according to the data derived from the observation of people in light clothes is:

$$Q_L = 2{,}51(35 - t_r) \tag{6.2}$$

The index of the heat exchange equal to 2,51 in this formula is near to the value which can be obtained by analytical calculation. The quantity of the heat emitted through radiation constitutes 42-44 % of the total quantity of the heat released. Despite the researches of Rubner, this method of heat exchange was not attached importance till 30th years. The similar analysis of the heat exchange through radiation was carried out by Aldrich, Bonencampf and Ernst, and Bonencampf and Paskan. They proved that the heat emission of the body through the irradiation happens according to the rules of Stephan -Boltzman. Daygon, Bedford and Hage, Hardy and Due Bua were also engaged in the researches on radiation heat emission and determination of its value. They obtained the result near to the results of Bonencampf.

The intensity of the convective heat exchange depends on temperature t_B and mobility V_B in the premises:

$$Q_K = 10{,}29\sqrt{V_B}(35 - t_B) \quad (6.3)$$

The convective heat emission constitutes nearly 32 – 35% of total heat emissions. The convection also includes the heat transmitted by the thermal conductivity, which as a rule is negligible, and therefore, will not be taken into account hereinafter. 2-3% of the convective heat is needed for the heating of the breathing air and its main part is produced by the surface of the skin and partially by clothes. If the temperature of the ambient air is higher than the body surface, then the human organism can perceive the convective heat.

The values of Q_k and Q_l are the components of "dry" or obvious human heat exchange. Their sum Q_{K+L} may be calculated from the following formula:

$$Q_L + Q_K = (2{,}51 + 10{,}29\sqrt{V_B}(35 - t_h) \quad (6.4)$$

where t_h– the temperature of the premises that is equal to:

$$t_h = (t_b + t_r)/2 \quad (6.5)$$

Formula (6.4) is fair for the conditions of the implementation of easy works in light clothes.

The effect of clothes of different weatherization on the value of Q_{K+L} may be taken into account using coefficient β_1. Its value will be approximately proportional to the relative resistance of heat transfer through clothes. For light clothes, the resistance of heat transfer from the skin surface through clothes to the premises is approximately equal to 0, 15, for ordinary clothes to 0,33 and for warm clothes to 0,5, accordingly. Averaging of the resistance values of heat exchange to the external surface of clothes in immobile air is equal to 0,17. Basing on these data, it is necessary to include the value β_2 equaling (0,5+0,17)/(0,33+0,17)=0,56 in formula (6.4) for ordinary (of medium warmness) and 0,42 for winterized clothes, accordingly. The calculation Q_{K+L} may be implemented taking into account correcting coefficients β_1 and β_2 according to the following formula for implementation of work of different severity in different clothes:

$$Q_L + Q_K = \beta_1\beta_2(2{,}51 + 10{,}29\sqrt{V_B}(35 - t_h) \quad (6.6)$$

This formula may be used for calculation of Q_{K+L} under special hot conditions (t_h>35º) when heat input is directed from the environment to human body.

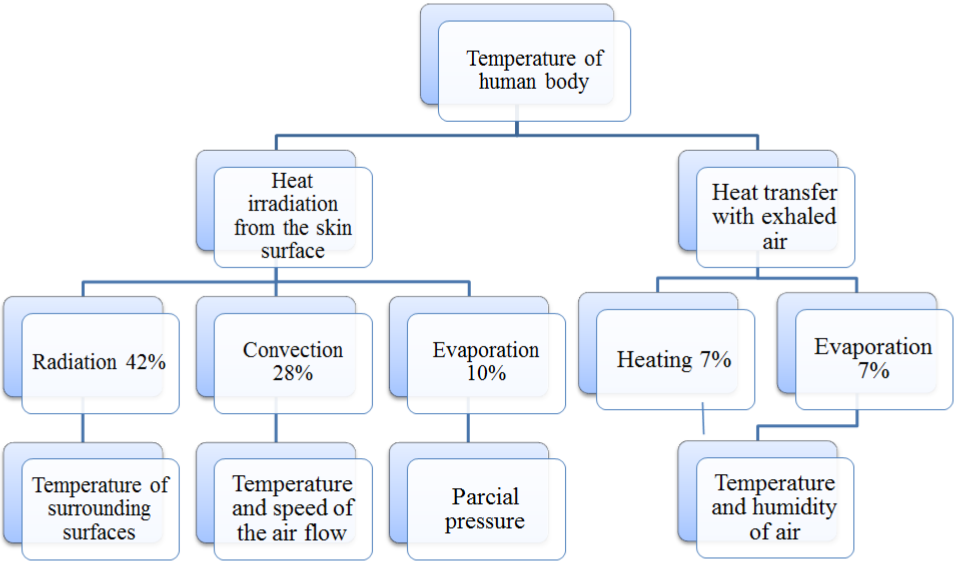
The heat transfer through evaporation may be divided into two components due to unseen evaporation (non-sensible perspiration) and sweating (sensible perspiration).

The organism evaporates nearly 800-1000ml [(8-10)$10^{-4}m^3$] moisture per a day that corresponds to 20-25% of the heat released under the conditions of main metabolism, as 2400 kJ heat is consumed for the evaporation of 1g water. Thus, the heat transfer through the evaporation per a day is nearly equal to (19.2-20)10^5J. At a temperature below the natural (i.e., nearer to the temperature of human skin), the quantity of the evaporated moisture remains practically permanent, but under the higher temperature conditions, moisture emission increases. Sweating begins at the air temperature 28-29ºC and at the temperature higher 34ºC, the heat transfer through evaporation and sweating is the sole method of heat transfer of the organism.

The sign of the value of heat transfer may be only negative during evaporation. The quantity of the temperature given out comes to 20-34% during evaporation at the temperature 23ºC. According to Aldrich, the radiation and convective components of heat transfer at the temperature from 18 to 24ºC ranges from 62 to 69% of total heat quantity. Thereby, the quantity of heat loss during evaporation amounts to 31 – 38%. According to the data of the last studies, these values make 20-25%. The heat loss during evaporation may be divided into two main parts: evaporation through the skin and through the mucous membrane of nose and throat.

The changes of the environmental conditions cause significant fluctuations in relation to separate constituents of the human heat transfer. While decreasing the air temperature and increasing the speed of its motion, a part of the convective heat transfer increases. But, the human organism begins to perceive the heat when the air temperature reaches 30-34ºC (i.e., higher than the skin temperature). According to the laws of the radiant heat exchange, the radiation heat output of human body increases when temperature of the enclosing surface decreases. The water vapor which at high concentration absorbs large quantity of the heat irradiated by body influences the radiant heat exchange. The intensity of heat transfer through the evaporation depends on the relative air humidity.

Pic. 6.1 A scheme of human heat exchange with the environment



7. THERMAL MICROCLIMATE OF BUILDINGS

7.1. Systems approach to the research of means and devices of thermal microclimate supply of premises

The thermal microclimate of buildings and facilities is provided by the engineering means and devices which include walling, filler structures and other constructive planning events, as well as cooling-heating, ventilation and air conditioning systems.For example in our study at TABRIZ city climate in IRAN, needed times and hours of the year to fan forced cooling ventilation has been calculated and analyzed by CLIMATE CONSULTANT program by inputting hour based climate factors data with EPW (*Energy Plus Weather*) file format, Diagram 7.1.

The purpose of the thermo-technical calculation of the thermal microcli mate of buildings and facilities is determination of the heat and sun control ling indicators of the filler structures, multiplicity of air exchange, power and work regime of the heating or cooling system of the premises required by sanitary-hygienic conditions. This purpose is achieved through thermo-technical calculation of separate fencings or via determination of heat loss or heat input through separate fencings in the traditional definition [20,21]. Due to world wide distribution of computers, effective methods have been developed for the microclimate calculation of the premises and buildings considering them as an integrated thermal energetic system [22-24]. Such kind of approach reflects the physical heat exchange process in building to a great extent and allows revealing new tools which were absent in separate elements of buildings.

The modern buildings represent a complex energetic system mainly consisting of different elements: enclosing structures, heating and ventilating devices; lighting systems, heliosystems, constructions of the artificial ice floe, technological equipment and so on. For example, the main features of the sports facilities are: high volume of the premises, lack of internal equipment with thermal capacity, thermal microclimate essentially variable within a day due to the temperature decrease and multiple air exchange at night time in the cold season of year or increase of the temperature at night time in the warm season of year. At the present time, the methodology of systems approach is widely used for the research and optimization of complex systems [25, 26]. In accordance with the systems approach methodology, in order to ensure the thermal microclimate of buildings and facilities through optimization of means and devices the researches should be implemented on the following stages [25]:

1. *Separation of the studied system (building or facility) from integrated system. At this stage the boundaries of the separated system shall be determined exactly and the general task of optimization of the means and devices and maintaining of the microclimate as well as the corresponding optimality*

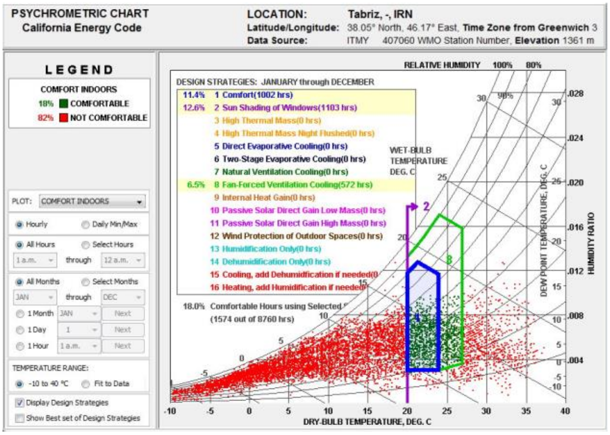
criteria shall be formed through the analysis of the objective tasks of its facilities and functioning.

2. *Ascertaining of the internal structure of the system, composition of its ele ments and the kinds of connection with each other. The purpose of this stage is to gain more distinct idea about the internal structures and features of the study object, i.e. establish the hierarchy of the system of a thermal energy object.*
3. *Aggregation of real elements and connections of the system allowing to establish hierarchy of the equivalent systems, each following level of which describes different parts of the studied system and in more aggregated form. The result of the works implemented at this stage may be the establishment of hierarchy of such kind of equivalent systems each including more closely connected elements of the initial system and at the same time available for research on its sizes.*
4. *Formulating of the structure of tasks solved with regard to every equivalent systems in different time levels. The purpose of this stage is distribution of variety of concrete tasks which shall be solved in the process of thermal energy object optimization upon the levels of the hierarchy.*
5. *Revealing of the composition and methods of interconnection of the equi valent systems within the framework of the constructed hierarchy. If they are considered in time sections, as these systems are the information equi valents of real thermal energy object or their separate parts, the connection between them obtains the form of the information connections described by approach of elements and technological relations of the objects in a varying degree. Consequently, the task of this stage is the formation of the hierarchy of the technical-economic information, i.e. determination of the composition of those indicators which are necessary for the optimization of each system and where it shall exchange with the rest system and the external environment.*
6. *Construction of the complex of models which serve as the instruments of decisions of the optimization tasks of each system and the heat energy object as a whole. Really, it is possible to carry out a range of researches on the behavior of each system and subsystem as a whole on the models and to realize complex, iterative process which is necessary for mutually coordination (with permissible error) of individual decisions of all systems of the hierarchy.*

At the present time, the mathematical models describing their features, elements and relations in the form of some equation systems, variable and logical conditions are applied for the optimization of developed and designed heat energy objects. These models are realized in computers. They provide a regulated (directed to the goal) search of the optimal decision, as well as decrease the quantity of considered variants of the designed heat energy objects in conjunction with use of different methods of mathematical programming.

In this case, the heat energy object of research is the premises of buildings and the sports facilities located in these premises (for example, artificial ice field). As the main elements of the object as the integrated heat energy system we will consider the followings: all the indicators of external climate, heat transfer in the enclosing structures, filtration of air through the enclosing structures, radiant and convective heat exchange in the premises, internal sources of heat (*heat input from the heating-cooling systems, absorption of heat by the artificial ice floe, heat emission from lighting sources and etc.*), heat persistence (inertia) of equipment located in the premises, thermal regime of the object as a whole.

Diagram 7.1: Hours needed for fan forced ventilation cooling in TABRIZ city



7.2. Parameters of the outside climate for calculation of the means and devices supplying the indoor thermal microclimate

The main parameters of the outside microclimate used for calculation of the means and devices supplying the indoor thermal microclimate of rooms, buildings and facilities are: the temperature of outside air, the intensity of solar radiation, the wind speed and the enthalpy of the outside air. The following values of the parameters of the outside microclimate are used for the calculation of thermal and sunscreen indicators of the outdoor enclosures, as well as their resistance against air and vapor permeability [20]: absolute minimal temperature of the outside air; average of colder days; average of colder three days; average of colder five days; average temperature of the outside air within the heating season, maximum amplitude of the temperature fluctuation of the outside air in July, maximum and average value of the total solar radiation (direct and diffuse), maximum from the average wind speed in July and January the repetition of which is 16% and more, but not less than 1 m\sec.

Following parameters of the outside microclimate are used for the calculation of the heating, ventilation and air conditioning [21]:

- *average temperature of colder period and heat content of air corresponding to this temperature and average relevant humidity of air of the coldest month at 13 h.;*
- *average temperature of colder five days and heat content of air corresponding to this temperature and average relevant humidity of air of the coldest month at 13 h.;*
- *absolute minimum temperature and heat content of air corresponding to this temperature and average relevant humidity of air of the coldest month at 13 h.;*

The followings were accepted for the calculation parameters of the outside air of warm period of year for cities and dwelling areas during the researches:

- *temperature and heat content of air which higher values in the given geographical point was observed on the average 400 hours and less in a year;*
- *temperature and heat content of air, which higher values in the given geographical point were observed 220 hours and less, and 200 hours and less in a year (the average for the long-term observations), respectively;*
- *absolute maximum temperature and heat content of air corresponding to this temperature (over many years) in the given point.*

Air temperature of the coldest days and the coldest five days is calculated according to the following method:

a) Choosing of air temperature in the coldest days and the coldest five days over 30-50 years according to the monthly tables of the meteorological observations and meteorological monthly magazines; air temperature of the coldest five days is determined by the choice of sliding five – days temperature;
b) The chosen data are placed chronologically, then in the descending order according to the absolute size with appropriation of every size in the serial number;
c) Air temperature of the coldest days and the coldest five days is rounded to 0,5°C, the number of cases and average serial number is determined for every interval;
d) The integral repetition (provision) is calculated according to the following formula:

$P = 1 - (m_{ave.} - 0{,}3)/(n + 0{,}4)$

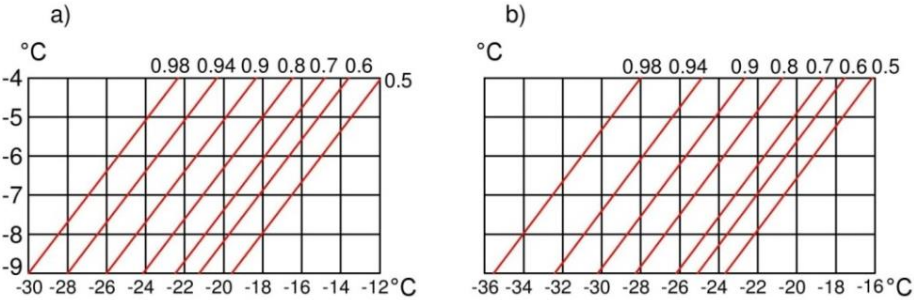
where P-the integral repetition (provision) in the shares of units, $m_{ave.}$ –average serial number, n-number of members of the row equal to the number of the observation years accepted for processing.

e) Drawing of integral air temperature distribution curves for the coldest days and for the coldest five days in the grid of asymmetric frequency: ordinate axis-logarithmic scale of air temperature, abscissa axis-double logarithmic scale of provision. The curves are drawn up to the provision value of 0,25;

f) The air temperature of both the coldest days and the coldest five days of the given provision are determined according to the curves.

Air temperature during the coldest days and the coldest five days with different provision for the points missed in the normative documents may be determined using universal graphics-climatic nomograms (picture7.1) presenting compact forms of the generalized large amount of information. The preciseness of the information obtained through nomograms depends on the dimensions of the evaluated territory. The density of the provision lines and their swings characterize the variability of the climatic parameters' values.

Pic. 7.1 Nomogram for calculation of air temperature of the coldest five days (a) and coldest days (b) of different provision



The duration of periods with average daily air temperature equal to or less than 0ºC (period with negative temperature), 10 ºC (heating period for medical, preschool and children institutions) and 8 ºC (heating period for other buildings) characterizes the duration of the period with stable values of these temperatures: separate days with average daily air temperature equal to or less than 0ºC, 8ºC and 10ºC are not taken into account. These data are calculated upon the curves of the annual variation of air temperature created according to the histogram method: the average monthly air temperature is described in the form of rectangles which basis is equal to the number of days of month and the height is equal to average air temperature for the given month. The curve of the annual variation is drawn so as the section which it passes through one end of the rectangle to be equal to the square of the section which is added to it from other side.

The dates of stable passage of the average daily air temperature are taken away from the graphic through 0, 8, 10ºC and the duration of the period during which the average daily air temperature remains stable lower than the given values are determined according to the differences between these data.

The sum of the air temperature per complete months of the heating period with addition of average monthly air temperature of the corresponding month to the number of days of this month is calculated for determination of average temperature of the heating period. Then, the sum of air temperature for in complete month of the heating period is calculated according to the curve of the annual variation of air temperature adding average air temperature of the corresponding section of time from the date of the beginning of the heating period till the end of a month (within the period of air temperature decrease) to the number of days of this section and the average air temperature from the beginning of month till the end of the heating period (within the period of air temperature increase) to the number of days of this section.

The average air temperature of the heating period is determined by dividing of the sum of the air temperature within the heating period to the heating period duration.

The average air temperature of the coldest period is calculated as average temperature of the period consisting of 15% of total duration of the heating period, but not more than 25 days.

Maximum from the average wind speed in January and minimum from the average wind speed in July (calculation wind speed) is determined as the highest from average speed in January the repetition of which comprises 16% and more and as smallest from the average wind speed in July the repetition of which comprises 16% and more.

Depending on the building destination and the features of the technological process, the designer may be interested in different indicators of deviations of the conditions in the premises from the calculated which can be: a) the indicators of the number of cases of deviation of conditions from the calculated in the general range of days, seasons and years taken under advisement by different reasons; b) the indicator characterizing general duration of deviation from the desired conditions within the calculation period (hours, days); c) the indicators characterizing the most unprofitable single deviation (the biggest duration and largest value of single deviations of any calculated parameter).

It is necessary to choose the heat – proofing quality of coverings, heat capacity of the heating system and etc. rightly in order to implement defined requirements on provision of set internal conditions. The choice shall be based on the calculations, the results of which are depending on the calculated external conditions. Thereby, provision of the desired internal conditions is determined by choosing the calculated parameters of the external climate.

The coldest period of each winter is called as "case". A range of cases of the preceding years is taken into consideration for choosing of parameters meeting certain probability of their appearance. The provision of conditions is determined by using a factor $K_{pro.}$, which value shows a share of the total sum of cases not allowing deviations from the calculated conditions. The parameters of climate for every case are associated with certain duration, therefore, it is also possible to characterize the durability of the calculated conditions through the provision factor. Comparison of the calculated conditions with the climatic parameters of maximum provision allows to find out both the value and duration of more deviations of possible conditions from the calculated conditions.

The values of the provision factor of the calculated conditions developed by V. N. Bogoslovsky for the cold and warm periods of year are presented in tables 7.1 and 7.2 [27,28].

Table 7.1 Provision factor of the calculated conditions for the cold period of year

Characteristic of main premises	Requirement level	Provision factor
Specially high requirements on sanitary – hygienic condition	Increased (I)	1
Round-the-clock presence of people or permanent technological regime	High (H)	0,9
Presence of people limited by time	Medium (M)	0,7
Short-time presence of people	Low (L)	0,5

Three gradations of climate (A, B and V) are accepted for the calculation of the microclimate provision system, which can be roughly characterized by the provision coefficients within the norms. The recommended gradation of the calculated internal conditions provision for summer period and their relation with the data of the corresponding regulations are given in table 7.2 [21].

The model of stochastic climatic influences for thermo-technical calculations of the outer enclosing structures of the buildings with the specified probability was developed by E.L. Deshko [29] and consists in the fact that all available calculation methods of the external fillers with the specified probability of no -failure work on the thermo-technical features are described by the operator equation:

$$\overrightarrow{I_{(M,A,B)}} = L(\vec{M}, \vec{A}, \vec{B}) \quad (7.1)$$

where I – vector of the space of calculated parameters, L – transformation operator; M-vector of the space of the meteorological influences, the components of which are: air temperature, intensity of solar radiation, wind speed, humidity and so on; A-vector of the space of thermo-physical and constructive characteristic of the external fillers (coefficient of heat conduction of materials, their density, humidity, geometrical parameters and etc.); B-vector of the space of the building inside parameters (air temperature, radiation temperature, humidity and air mobility or complex indicators of the microclimate).

Table 7.2 Required provision and its relation with the gradation of climate

Requirement level	$k_{0\rho}n$	$\Delta z, r$	$k_{ob}, \Delta z$	Gradation of climate according to regulations
Increased (I)	1	0	1	H
High (H)	0,9	50	0,98	B
Medium (M)	0,7	200	0,92	
Low (L)	0,5	400	0,8	A

The methods are classified according to the number of parameters taking into account while developing the calculation models, methods of transformation of the baseline information and output parameters of the calculation method (table 7.3).

Participation of vector A in the model leads to the results corresponding to concrete constructions of the external fillers within the admitted assumptions in calculation of heat conduction and modeling of the components of the vector M without interconnection with other vectors allow to get the initial information for different structures of the external filler. Unsteadiness of heat conduction of the external filler structures conditioned by the dynamic of the external climatic influences requires elaboration of corresponding stochastic models of meteoregimes. Stochastic modeling of the meteoregime is possible on the basis of the correlation dependence or its imitation by the method of Monte-Carlo. But application of the Monte-Carlo method in practice requires implementation of big volume of computation for calculation of meteoregime during designing of different filler types. The models allowing to calculate temporary components of the vector M have been elaborated by the authors taking into account the correlation dependence between them with specified probability of their realization.

The features of unsteady thermo-technical external structures determine the necessity of hourly view of the values of meteoelements taking into account their stochastic interconnection with defined provision norms.

In order to get reliable date on the probabilistic characteristics of accidental processes of meteofactors' variation the required number of their realization should be revealed. It is admitted to consider reliable the results obtained from more than 200 realizations. Therefore,observation for seven years will be enough during modeling of the daily dynamics of microelements of the calculation month. The automatic correlation function is calculated on the basis of meteo observations:

$$k_{x,x} = (t_i, t_j) = M[x^0(t_i)x^0(t_j)] \quad (7.2)$$

where $k_{x,x}(t_{i,} t_j)$ - the value of the automatic correlation function for moments $t_{i,}$ and t_j; M – calculation operator of the expected value; x^0 (t_i) – value of meteoelement x (t_i) at the moment of t_i time centered relative to its expected value, i.e., x^0 (t_i) = x (t_i) – M x (t_i)

The value of the automatic correlation function of discrete stochastic process determines the automatic correlation matrix $[k_{x,x}(t_{i,} t_j)]$ according to which the matrix of reverse automatic correlation relation $[L_{x,x}(t_{i,} t_j)] = [k_{x,x}(t_{i,} t_j)]^{-1}$ allowing to estimate the degree of the linear dependence between the hourly values of meteoelements and to get the coefficient of the linear autoregression modeling the variation of values of meteoelements within days is calculated.

Calculation of their daily norms Σ_{xi} is considered for each realization for revealing of stochastic interconnections between microelements in the model. Modeling comes to revealing of the statistic characteristic of the meteocomplex presented in the form of selective values of the random variables by implementing this procedure for realization of the considered meteoelements, particularly for calculation of the external filler structures, air temperature, direct and diffuse solar radiation and wind speed. Afterwards, the matrix of covariance $[l_{ii}]$, correlation $[R_{ik}]$, as well as the matrix of reverse covariance $[L_{ii}]$ are calcu lated by generally known formulas. The degree of dependence between the elements of meteocomplex is verified according to the consolidated coefficient of the correlation calculated by the following formula:

$$r_{(x_i)} = \sqrt{1 - \frac{1}{l_{ii}L_{ii}}} \quad (7.3)$$

Non-correlated elements of meteocomplex which allow to look through them as independent elements beforehand are defined at this stage of the calculation. The final conclusions about the dependence degree of meteo elements are made on the basis of private coefficients of the correlation determined from the following expression:

$$r_{ik} = -L_{ik}/\sqrt{h_{ii}} \tag{7.4}$$

The hypothesis of non-correlativity between the meteo elements is verified according to statistic *y* having the Student distribution with n-1 freedom degree:

$$t = \sqrt{n-1}r_{ik}/\sqrt{1-r^2ik} \tag{7.5}$$

where n – the scope of realization.

Verification of the hypothesis is implemented at a selected level of signi ficance usually accepted as 1 and 5%.

Table 7.3 Classification of the probabilistic calculation models

Initial information	Transformation operator	Calculation parameters
Meteorological data of many years (components of the vector M)	Statistical processing	Function of division of meteofactors (FM)
Many years observation over meteoregime and main characteristic of the premises (components of the vectors $\vec{M}, \vec{A}, \vec{B}$)	Calculation of heat loss of the premises and statistic processing of the obtained data	Function of the division of complex indicators of the external influences (FM)
Meteorological data of many years and main characteristics of the external filler (components of the vectors $\vec{M}, \vec{A}, \vec{B}$)	Calculation of main characteristic characteristics of the external filler structure and their statistic elaboration	Function of the division of main characteristics of the external filler structures (IAB)
Meteorological data of many years and model of thermal regime of the premises (components of the vectors $\vec{M}, \vec{A}, \vec{B}$)	Calculation of the parameters of the internal environment and their statistic elaboration with imitation of components of the vectors A, B by the method Monte Carlo	Function of the division of parameters of the internal environment (IB)
Meteorological data of many years (components of the vector M)	Imitation of the meteoregime by the method Monte Carlo	Synthetic temporary series of the internal influences (IM)
Meteorological data of many years and model of functioning of the object (components of the vectors $\vec{M}, \vec{A}, \vec{B}$)	Modeling with involvement of the theory of Markovian accidental processes	Dynamic characteristics of functioning of the object (IB)

One of the main stages of modeling is the determination of the type of the function of division of each meteoelements for which the empiric functions of density of distribution are drawn and approximated with the known theoretical curves. The degree of correspondence between them is controlled according to the criterion of accordance on the selective level of significance, particularly according to the criterion x^2. The form of the distribution function for each of them gives the basis to make a conclusion on the form of function of their joint distribution during correlation of dependence between meteo elements. In the most cases the function of normal distribution is characteristic.

It is necessary to determine the components of the vector A for all vectors related to the field Д for determination of the vector M and to choose such kind of vectors which can provide the probability of no-failure operation equal to 1 for revealing of the correspondence of probability of the external influences P(M) to no-failure operation of the external filler structures P (A). Formally, it is necessary to implement similar calculation for all vectors of the field, but it is practically possible to reveal the characteristic vector $M_{од.}$ Providing the condition $P(A_д)=1$. The probability $P(\overrightarrow{M_D})$ is intersection events meaning inclusion of the components of the vector M under consideration to the field D, i.e.:

$$\mathrm{P}(\overrightarrow{\mathrm{M_D}}) = \mathrm{P_D}(\mathrm{T} \cap \mathrm{I_P} \cap \mathrm{I_R} \cap \mathrm{V}) \tag{7.6}$$

where T – the daily temperature norm of the external air; I_P, I_R – daily norm of the direct and diffuse solar radiation; V – daily norm of the wind speed.

In the practical calculations, some cases don't intersect, then the probability is appointed as the same for each of them so that the defined general probability could be provided. In case of intersection of the events for selected main component of the vector M (during calculation of the external filler structures – temperature of the external air) there is the meaning upon the distribution function in accordance with the probability received taking into account the correction on probability of reliable determination of the dependant components from the regression level.

The dependant systems are found from the system of the linear equations each of which has the regression of meteoelements to the others correlated with them. Obtained values are the estimations of the expectation value of the dependant components for found value of the main components. The spread of values of meteoelements from their expectation values is considered as correction determined by joint function of distribution for selected confidence probability. In the concrete cases for normal distribution law, the correction may be implemented through the ellipse of equal probabilities.

Hourly values of meteoelements X (t_i) are determined from the equations of linear autoregression and condition that their sum is equal to the above-mentioned found daily norms of meteoelements. Practically, it combines with the decision of the system of equations:

$$\sum_{i=1}^{n} \chi(t_i) = S_i$$

$$\sum_{\substack{k=1 \\ i\neq 1}}^{n} \beta_{ik} X^0(t_i) = 0 \qquad (7.7)$$

where n – the number of digitization points, β_{ik} – coefficient of the linear autoregression determined according to the following formula:

$$\beta_{ik} = \frac{L_{x,x}(t_i,t_k)}{L_{x,x}(t_i,t_i)} \qquad (7.8)$$

7.3. Radiant heat exchange in premises

It is necessary to use the method basing on determination of effective radiation [27] for exact calculation of the radiant heat exchange of body with the surfaces surrounding it in the premises.

General flow of heat leaving the surface due to the radiation is called the effective radiation E_{ef}. This flow is consists of the flows of own E_{ow} and reflected E_{ref} radiation. The radiant flow coming to the surface is called as falling E_{fa}. It presents the sum of the flows of effective radiation of all surrounding surfaces. One of its part remains on the surface and is the absorbed radiation E_{tak}.

The balance of the radiant heat exchange L_1 of the unit surface in the premises with all surfaces is determined by the equation:

$$L_1 = E_{tak} = (E_{ef1} - E_{fa1})F_1 \qquad (7.9)$$

The effective radiation of the unit surface is equal to the sum of own E_{ow1} and reflected E_{ref1} radiation:

$$E_{ef1} = E_{ow1} + E_{ref1} = \epsilon_1 C_0 (\frac{T_1}{100})^4 + (1 - \epsilon_1) E_{fa1} \qquad (7.10)$$

The heat exchange of the radiation of the unit surface with the rest surfaces of the premise may be presented in the following form. The amount of heat leaving the unit surface is determined as $\Sigma F_1 \varphi_{1-j} E_{ef}$. The amount of heat fallen on the unit surface is equal to $\Sigma F_j\ \varphi_{1-j} E_{efj.}$ Taking into account the features of interconnection of the radiant flows when $F_j\ \varphi_{1-j} = F_j\ \varphi_{1-\varphi}$, we have:

$$\sum_j F_1 \varphi_{1-J} E_{ef1} = \sum_j F_1 \varphi_{1-J} E_{efj} \qquad (7.11)$$

The balance of the radiant heat exchange of the unit surface in connection with it may be written according to (7.9) in the following form:

$$L_1 = \sum_j F_1 \varphi_{1-J}(E_{ef1} - E_{efj}) \quad (7.12)$$

The joint decision of equations (7.9) and (7.12) allows to determine the connection between E_{01} (radiation of absolute black body at the temperature of the surface 1°C) and effective E_{ef1} radiation of the surface and to write down the balance of the radiant heat exchange on it in the following form:

$$L_1 = F_1 \frac{\epsilon_j}{1-\epsilon_j}(E_{01} - E_{ef1}) \quad (7.13)$$

Thereby, the radiation of the grey surface is determined by two flows of radiation E_{01} and E_{ef1} and its balance of the radiant heat exchange-by equations (7.12) and (7.13).

Let's include the conditional concept "effective temperature T_{ef} of the surface". According to the analogue of dependence between E_{01} of the surface and its temperature T_1:

$$E_{01} = C_0 (\frac{T_1}{100})^4 \quad (7.14)$$

Dependence between the effective radiation of the surface E_{ef1} and its effective temperature T_{ef1} will have the following form:

$$E_{ef1} = C_0 (\frac{T_{ef1}}{100})^4 \quad (7.15)$$

It is convenient to write down the equation of the balance of the radiant heat exchange relative to the variation of temperature.

Equation (7.12) will have the following formula:

$$L_1 = \sum F_1 \varphi_{1-J} C_0 \, b_{ef_l - ef_j} \left(T_{ef_l} - T_{ef_j}\right) \quad (7.16)$$

And equation (7.13) will have the following formula:

$$L_1 = F_1 \frac{\epsilon_j}{1-\epsilon_j} C_0 b_{1-ef_j} \left(T_1 - T_{ef_j}\right) \quad (7.17)$$

where T_1, T_{EFj} – corresponding temperature and effective temperature of the unit surface and surrounding its surface, °C; b-temperature coefficient taking into account in equations (7.16) and (7.17). Solution of the problem may be achieved through the analogous electric model or the calculation in the computer.

It is possible to simplify the problem definition disregarding reflected secondary radiation for the engineering calculation of heat exchange in the cases when the surfaces have high coefficient values. Usually, the blackness degree is more than 0,9 for the filler structure in the premises, therefore, the reflected secondary radiation has very small size from the fallen flow and significantly less than its own radiation. If the surfaces have small coefficient of blackness, then the share of the radiant heat exchange decreases in the general heat exchange and therefore, increase of error in the calculation of the radiant components doesn't practically change the exactness of the general results. Calculations upon exact formulas show that neglect of repeated reflections applicable in the conditions in the premises give small errors (less than 3%) are totally allowable in the engineering calculations [25]. Accepting such kind of simplification, it is possible to determine the radiation balance of the unit surface in the premises taking into account the heat exchange from all surfaces according to the following formula:

$$L_1 = \sum_J C_0 \in_{1-j} b_{1-i}(T_1 - T_j)\varphi_{1-j}F_1 \quad (7.18)$$

All surfaces shall be taken into account during calculation, and in the following cases their characteristic parts engaged in the radiant heat exchange with the unit surface shall be considered. The number of the surfaces and their parts will be according to the number written in the sum of the right part of the equation and may be great enough and it makes it difficult. In connection with it, it is convenient to use the notion radiation temperature t_R in the premises for the consecutive simplification of the calculation of the radiant heat exchange of the surface. t_{R1} temperature-the radiation temperature of the premises relative to the unit surface that is determined as the averaged temperature of all surrounding surfaces of the premises. The sign of the equivalency of the radiant heat exchange quite fully reflects the radiation coefficient (7.18). Therefore, t_{R1} is determined as the averaged temperature of the surface according to the coefficient of radiation:

$$t_{R_1} = \sum \varphi_{1-j}t_j / \sum \varphi_{1-j} \quad (7.19)$$

The denominator of the last formula is usually equal to the unit on its feature of reticence of the radiant flows, therefore,

$$t_{R_1} = \sum \varphi_{1-j}t_j \quad (7.20)$$

Sometimes, t_{R1} is determined as an average temperature upon the square of the surrounding surface, i.e.

$$t_{R_1} = \sum F_j t_j / \sum F_j \quad (7.21)$$

Calculation by (7.21) is simpler than by (7.19), but less exact. Using the notion "radiation temperature", we can further simplify the calculation of the radiant heat exchange in the premises and to write formula (7.18) in the following form:

$$L_1 = C_0 \in_{w_{1-R}} b_{1-R}\varphi_{1-R}(T_1 - t_R)F_1 \quad (7.22)$$

The physical meaning of production of values before the variation of temperature in this formula consists in the fact that it is the coefficient of the radiant heat exchange of the unit surface in the premises ($\alpha_{л\,1}$) which is equal to:

$$a_{l_1} = C_0 \in_{w_{1-R}} b_{1-R}\varphi_{1-R} \quad (7.23)$$

Taking into account α, we write down the equation of the radiant heat exchange of the random unit surface in the premises in the following form:

$$L_1 = a_{l_1}(T_1 - t_R)F_1{}^{`} \quad (7.24)$$

The surfaces turned inward of the premises are characterized by the following parameters: ε≈0.9-0.95; ε_{w1-R}≈0.85; b_{1-R}≈1; φ_{1-R}≈1; C_0 5.77, therefore, $\alpha_{l\,1}$≈ 5.77·0.85 · 1·1 = 4.9 W/(m^2 · °C). This value $\alpha_{l\,1}$is usually accepted in the engineering calculations of the radiant heat exchange in the premises.

7.4. Convective heat exchange in premises

The convection plays an important role together with the radiation in the total exchange in the premises. Supply and emission of air in the ventilation system strengthens the process.

In the majority of premises, as a result of air mixing uniform distribution of the temperature t_B in the horizontal and vertical directions is observed. It allows to accept its same values during calculation of the heat exchange on all surfaces. The premises with significant excess and transmission of heat through non-isothermal stream are excluded. In this case, unequal distribution of temperature on the height takes place, but it is observed in the plan of the premises during local placing of the heat source. Convective flows of warm air arise over the sources forming the stratum of heated air (thermal cushion) under the ceiling.

Heat exchange in premises significantly influences the aerodynamic pro cesses happened under the influence of non-isothermal streams. Ventilation and thermal streams interact between themselves and also with enclosures and other subjects in the premises. As a result of this interact, air circulation happens in the premises and certain speed and temperature fields are formed. Their calculation may be implemented on the basis of laws of conservation of the quantity of motion, mass and energy. The relation between the number of movements of the elementary volume and the powers influencing them is determined for the first: surface P (pressure, friction) and external mass F (gravitation, centrifugal and gravity).

Development of air flows in the enclosures has certain specification. These flows occur when the heated or cooled surfaces are available in the premises or during discharge of non-isothermal incoming stream along the surfaces. In this case, the air flows occur due to the variation of air density on the surface and in the space of the premises which leads to emergence of the buoyancy (Archimedean) force and air motion along the surface. In the second case, the source of motion is the initial impulse obtained from the particles of air when it is discharged from the incoming devices. The wall and jet (external) boundary layers are distinguished in this parietal flows. In this case, irrespective from the degree of turbulence of the jet flow the wall always has viscous laminar sub - layer where the friction power associated with the viscosity of the fluid is essential. All parietal boundary layers are full with the fluid sub-layer near the outflow. The thickness of the parietal boundary layer increases in the direction of the air motion. Vortexes begin to be formed on the parietal boundary layer and leads to turbulization at some distance from the beginning of the flow. Laminar boundary layer passes to turbulent which keeps only some vis cous sub – layer near the surface.

The convective current that causes heat exchange between the surface and air appears near the heated and cooled, freely placed on a large scale surfaces. This process is called as the free convection. The intensity of free convection is determined by the coefficient of the convective heat exchange α_c the average value of which is equal to the following like its local value in the areas of automodel [22]:

$$a_c = 1{,}66\sqrt[3]{\Delta t} \tag{7.25}$$

Average value of the convective heat exchange coefficient on the vertical surface of the enclosures may be determined without any error by formula (7.25), because mainly turbulent regime corresponds to the temperature drop and the geometrical dimensions of the heated and cooled surfaces actually taking place. Formula (7.25) is written for vertical, freely placed surfaces.

It is experimentally determined that it is possible to use formula (7.25) during horizontal placing of the heated or cooled free surfaces for the calculation of the average intensity of the heat exchange, but in this case, the value of the numerical factor shall be changed as follows:

Surface	***Values of numerical coefficient in (7.25)***
Vertical	1,66
Horizontal, turned upwards:	
heated	2,26
cooled	1,16
Horizontal, turned downwards:	
heated	1,16
cooled	2,26

General mobility of air in the premises influences the intensity of motion of the convective flow near the surface. The Mac – Adams law according to which during joint influence of free and forced convection (general air motion in the premises is considered as the forced motion) most private values of the heat exchange coefficient determined for free and forced convection should be taken into account is often applied in heat exchange. This law shall be used when the frontal flow around surface takes place. It is possible to determine the coefficient of the convective heat exchange through calculating the speed of air near the surface by adding total air mobility in the premises with its movement caused by the temperature variation during direction of the forced motion along the surface.

The mixed air motion along the surface may be characterized as the conditional temperature Δt_{con} the value of which causes the same intensity of the convection current like during natural convection taking into account the total air mobility in the premises:

$$\Delta t_{con} = \Delta t + \Delta t_V \quad (7.26)$$

where Δt-the temperature variation between the surface and air; Δt_v-tempe-rature variation, equivalent to the air motion in the premises.

Formula (7.26) may be used during calculation of heat exchange both on the vertical and horizontal surfaces, as the value Δt_v entered to it takes into account the total air circulation in the premises. The natural convection may be calculated according to formula (7.25) for free convection using the value Δt_{con} instead of Δt under the total mobility of air in the premises.

7.5. Heat and sun protective quality of fillings of light apertures

The main purpose of glazing is that light shall enter to the inside space of the premises and at the same time to establish visual contact of people with the outside world, as the events seen through the window widen the living space of the limited interior.

The requirement on the transparency of glasses leads to the fact that the heat isolating features of the glazed areas are worse than other outside en-closures of the building: three times in comparison with the heat isolating walls and five times in comparison with the roof (according to the minimum norms of heat isolation). During the heating period the temperature of the internal surface of the usual window pane is lower for some degrees than the temperature of walls. The human body exchanges heat uninterruptedly with all surfaces and it becomes more effective when the temperature variation between these surfaces is large. Therefore, first of all the heat exchange happens between people and glazed areas and as a consequence the temperature of the body surface decreases causing discomfort feeling of cold. The air temperature in the room is increased for elimination of this phenomenon. Increase of temperature by one degree leads to 5% increase of the annual expenditures on heating which depends on the variation of the external and internal temperature. But, glazing exerts double effect on the power consumption for the building heating. On one hand, heat loss takes place through the glazed area of windows, on the other hand, insolation influences the air temperature in the room and consequently, on the whole thermal power consumption for heating.

It is known that, 70% of the heat loss through the usual glasses happens due to long wavelength thermal radiation, and the rest 30% due to the heat conduction and convection. In the usual windows with double frames the heat transfer happens through the following ways:

1. *In the form of long wavelength radiation;*
2. *Convection to the internal glass;*
3. *By means of the heat conduction through the internal glass;*
4. *The heat transfer happens in the air gap of the windows by means of the heat conduction and convection in the filling gas, as well as through radiation between external and internal glasses;*
5. *The heat is transferred by means of the heat conduction through the external glasses;*
6. *The heat is taken from the external surface of the external glasses through emitting to the environment;*
7. *The heat of the external surface is transmitted through the natural and forced convection to the* surrounding environment.

The features of glasses exert great influence on the character of heat exchange. The latter is covered by selective materials to decrease the radiation capacity. The feature of the selective glass has special significance within two ranges of the long wavelength. The first one corresponds to the short wavelength thermal radiation with λ=0,2-2 mkm. This range of waves is important, as the optic disc of eyes of people distinguish color in the range λ=0,38-0,76 mkm. Maximum sensitivity of the optic disc is 0,55 mkm. This value is chosen often as the length of the wave by which the coefficient of light transmission is determined.

The second range corresponds to the value of λ=2,5-16 mkm, where the reflection is the most important feature of the glass with selective cover.

The selective surface may be formed by putting oxide layers and also thin metallic layers on the glasses. The glass is first covered by the semiconductor film while putting the oxide layer. In_2O_3 and SnO_2 are widely used as the selective materials, wherein the thickness of the layer changes within (4-6)·10^{-7} m. Cd_2SnO_4 also has the corresponding features, but due to high toxicity, its application didn't exceed the range of the laboratory experiments. Also, MnO, NiO, SiN, PbO, $SiFeO_3$, Cr_2O_3, WO_3, CdO, Cu_2S, ZnO, Bi_2O_3 and other compounds may be used for this purpose.

In order to evaluate their capability of reflecting the long wavelength heat radiation the following requirements are made to the coverage materials: density of free electrons 3 x 10^{23} particles/ cm^2; mobility 4 x 10^{-3} m/(c · W)

Metals having high power conduction also fit for selective coverage. Au, Ag, Cu are specially comfortable, since they have free sole electron in their S – cover. Al, Zn, Co can also be used as coverage.

The resistance of heat transfer of the glazed area is usually calculated by the known formula:

$$R_0 = \frac{1}{\alpha_B} + R_i + \frac{1}{\alpha_H} \tag{7.27}$$

where R_0 - the resistance of heat transfer, $m^2 \cdot {}^\circ C/W$; α_H-coefficient of heat transfer of the external surface, $W/(m^2 \cdot {}^\circ C)$;α_B-coefficient of heat transfer, $W/(m^2 \cdot {}^\circ C)$; R_i-thermal resistance of the glazed area, $m^2 \cdot {}^\circ C/W$.

The values of α_H and α_B depend on permanently changing climatic conditions and the geometry of window opening. The following correlation can be used for comparison of different constructions of the glazed areas, $m^2 \cdot {}^\circ C/W$:

$$\frac{1}{\alpha_B} + \frac{1}{\alpha_H} = 0{,}2$$

The thermal resistance of the glasses is conditioned by the influence of different factors. The heat exchange coefficient m_i may be calculated by the following formula:

$$m_i = \sum_1^n \frac{1}{h_s + h_k} + \frac{s_l}{\lambda_l} \tag{7.28}$$

where n-the number of air spaces, h_S-coefficient of heat transfer by the radiation, $W/(m^2 \cdot {}^\circ C)$; h_k-coefficient of heat transfer through heat conduction and convection, $W/(m^2 \cdot {}^\circ C)$; s_l-complete thickness of glasses, m; λ_1 – heat conduction of glasses, $W/(m^2 \cdot {}^\circ C)$.

The heat conduction of the glasses is higher than the heat conduction of the air space, therefore, the last summand may be neglected in formula (7.28).

The coefficient of heat transfer of the radiation, W/($m^2 \cdot$ K) is calculated according to the following formula:

$$a_s = \frac{4\sigma t^{-3}}{\frac{1}{E_1}+\frac{1}{E_2}-1} \qquad (7.29)$$

where σ – the Boltzmann constant equal to 5,73 x 10^{-8} W/($m^2 \cdot {}^oC^4$); E_1 and E_2 -coefficients of the emissivity of the surfaces participating in radiation; t – medium temperature, °C.

Table 7.4 Resistance of heat transfer R_0 and the coefficients of light transmission for traditional glazed constructions

Glazed construction	R_0 ($m^2 \cdot {}^o$ C) /W	Coefficient of light transmission,%
Simple usual glass	0,17	90
Ordinary frame:		
double	0,32	81
triple	0,48	73
quadruple	0,67	66
Double glass pane with selective cover with small E value:		
with double glasses	0,63	74
with triple glasses	0,83	66
with triple glasses + simple glass	1	66

The value of the coefficient of the heat transfer of the radiation for the glazed areas with double heat isolated window frames depending on the radiation capacity of the selective glasses E_1 during constant radiation capacity of the ordinary glasses E_2=0,85 is given below. The temperature variation between the surfaces participating in radiation is equal to 20 °C.

E_1	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8
h, W/(m^2.K)	0,51	1	1,48	1,94	2,38	2,82	3,24	3,64

The coefficient of heat transfer with heat conduction and convection is calculated according to the following formula:

$$a_k = \frac{Nu\lambda}{s} \qquad (7.30)$$

where Nu – Nusselt number, λ-heat transfer of gas filling the air space, W/($m^2 \cdot {}^o$ C); s – width of the air space, m.

The value of heat transfer with heat conduction and convection in the heat isolated window frame is given in table 7.5 depending on the thickness of the air space at the height equal to 1 m and 20°C difference of temperatures.

Table 7.5 Coefficient of heat transfer h_k, W/(m^2 ·°C)

Filler gas	Width of the air space s, mm			
	6	9	12	15
Air	4,13	2,76	2,07	1,94
SF_6	2,9	2,72	2,62	2,54
Ar	2,8	1,87	1,44	1,39
Kr	1,42	1,01	0,88	0,95

The Nusselt number related to gas in the air space is determined as:

$$\mathrm{Nu} = 0{,}1954\ (\mathrm{Gr} \cdot \mathrm{Pr})^{0{,}25}(\mathrm{s/h})^{0{,}111} \qquad (7.31)$$

where Gr-Grasgof number, Pr-Prandtl number, h-height of the air space, m.

Grasgof number is calculated by the following formula:

$$\mathrm{Gr} = \mathrm{s}^3\Delta\mathrm{tg}(\mathrm{v}^2\mathrm{t})^{-1} \qquad (7.32)$$

where Δt – the temperature difference between the surfaces participating in the radiation exchange, °C; g – acceleration of free fall equal to 9.81, m/s^2; v – kinematic viscosity of gas, m^2\s; t – average temperature of gas, °C.

Kinematic viscosity may be determined according to the following formula:

$$\mathrm{v} = \frac{\mu}{\rho} \qquad (7.33)$$

where μ-the dynamic viscosity, kg/(m·s); ρ-density of the filling gas, kg/^{m3}.

At Gr·Pr<5·10^3 the Nusselt number is equal to 1, i.e., only heat conduction is taken into account. When Gr·Pr<5·10^3, heat transfer is taken into account as heat conduction, as well as convection that is considered in formula (7.30).

Table 7.6 Features of the filler gas in the air space of the heat isolated glass

Filler gas	Heat conduction, W/(m^2 · ° C)	Dynamic viscosity, kg /(m^2 · c^2)	Density, kg/m^3	Prandtl number
Air	0,0025	17*10^{-6}	1,28	0,75
SF_6	0,013	14,6*10^{-6}	6,6	0,69
Ar	0,016	21,2*10^{-6}	1,76	0,66
Kr	0,0085	22,9*10^{-6}	3,39	0,67

During preparation of double glass panes with selective cover, the metallic frame of the block is made of aluminum or galvanized steel.The heat conduction of this frame influences the total coefficient of the double glass pane. The coefficient of heat transfer of such kind of construction of the double glass pane is equal to 5W/(m^2·°C), and in the block with 1000x1000mm^2 dimensions is nearly 5% of the total square of the frame. The values of thermal resistance R_0 of the double glass pane having low E value (emissivity of one glass is equal to 0,1 and of other to 0,85) are given in table 7.7

The data about duration and intensity of the external thermal effects are initial materials for the thermal engineering calculation of the building enclosures, as well as for solution of a number of other problems of the construction physics. .

The density of the flow of fallen solar radiation changes within wide limits depending on the height of standing of the Sun and incidence angle of the sun beams on the irradiated surface.

Table 7.7 Resistance of the heat transfer of the glazed area of double selective heat isolating glazed frame

Filler gas	Width of the air space s, mm			
	6	9	12	15
Air	0,42(0,39)	0,51(0,46)	0,59(0,53)	0,61(0,54)
SF_6	0,5(0,45)	0,51(0,47)	0,52(0,47)	0,53(0,48)
Ar	0,5(0,46)	0,62(0,55)	0,71(0,62)	0,73(0,63)
Kr	0,72(0,62)	0,85(0,71)	0,87(0,72)	0,88(0,81)

Note: *The data taking into account 'cold bridge" of the frame is given in the brackets.*

The solar radiation may be divided into two main forms according to their character of influence: direct and diffuse. The latter consists of the diffuse and reflected radiations. The notion of total solar radiation is used during combined consideration of direct, diffuse and reflected radiation.

At the present time, the components of the solar radiation are determined according to the data of many-years observation of the network of the meteorological stations that fix the total entrance of direct and diffuse radiation on the horizontal surface. The formula of Kastrov-Savinov and so on are applied for calculation of direct solar radiation fallen on the enclosures with different orientation. In practice, the use of factual data on the solar radiation significantly simplifies the insolation calculations compared to the calculations implemented in the equatorial system of coordinates, therefore, it is widely applied in the domestic architectural – construction designing.

In the literature, the background materials (coordinates of the Sun, value of the solar radiation intensity) necessary for the calculation of insolation are usually provided on average solar time which are convenient for practical applications (table 7.8).

Table 7.8 Difference between the average solar and discrete time Δz

City	Time, hour - minute	City	Time, hour - minute
Almaty	0-52	Namangan	1-14
Andijan	1-11	Nukus	1-02
Ashkhabad	1-06	Samarkand	0-32
Bucharest	0-42	Tashkent	1-23
Dushanbe	1-25	Termez	0-31
Karshi	0-37	Fergana	1-13
Krasnovodsk	2-24	Frunze	1-02

The density of the direct radiation flow entered to the vertical enclosure depends on the orientation of the enclosure and is calculated according to the following formula:

$$I_P^B = I_P^Q \mathrm{ctg}\beta_0 \qquad (7.34)$$

The data on the solar energy entrance [30] to the horizontal surface characterize more probable solar heat input taking into account the cloudiness and typical condition of atmosphere for the considered place.

Arrival of the diffuse radiation on the facade of the building is usually accepted as equal to half of the heat input of this kind of radiation on the horizontal surface. It can be considered fair only in connection with the enclosures of the northern orientation. In the general case, heat input from the diffuse firmament of the solar radiation onto the vertical enclosure is the function of the coordinates of the Sun and is calculated according to the following formula:

$$I_R^B = I_R^Q k_{ill.} \qquad (7.35)$$

The illumination coefficient of the enclosures is determined by the following empiric formula:

$$k_{ill.} = 0,55 + 0,437 \cdot \cos\theta + 0,313 \cdot \cos^2\theta \qquad (7.36)$$

Illumination coefficient of the vertical enclosures is shown below.

The angle of incidence of the sun beams, grad	0	10	20	30	40	50	60	70	80	90
$k_{ill.}$	1,3	1,28	1,24	1,16	1,07	0,96	0,85	0,73	0,63	0,56

It is obvious from these data that the vertical enclosures oriented in the southern direction obtain nearly twice less diffuse radiation of the firmament than the horizontal surface and the enclosures oriented to the eastern and western sectors of the horizon according to sunrise and sunset hours undergo to more intensive influence of the radiation than the horizontal surface.

The facades of the buildings get additional thermal load conditioned by the reflection of the sun beams of the underlying surface and the enclosures of the surrounding buildings.

The engineering method of calculation of the reflected solar radiation are developed and suggested under the conditions of town building by a group of researchers under the leadership of the doctor of sciences A.V. Ershov [5]. In essence, the number of this type of heat input is the function of the total solar radiation fallen on the considered surface, its albedo and depends on mu tual situation of the surfaces which reflect and perceive heat:

$$I_O^B = \sum_{i=1}^{n} I_{sum_i} p_i \varphi_{i-b} \qquad (7.37)$$

where $I^B{}_0$-the density of the flow of the reflected solar radiation fallen on the vertical enclosure, W/m^2; I_{sumi}-the density of the flow of the total solar radiation fallen on i^{th} reflected surface W/m^2; ρ_i-albedo of i^{th} surface; φ_{i-b}-angle coefficient between the vertical enclosure and i^{th} surface.

Among the regulated solar protecting devices, a great part consists of the devices of the screen type-sun blind, curtains-venetian blind, drapery. The products made of special glass and plastic heat reflecting and heat absorbing glasses, and building glass stones can be used for this purpose, as well.

The thermo-technical calculation of solar control is required for the analysis of the internal temperature in the designed building, for comparison of the efficiency of the devices of different types or determination of loads on the conditioning system. While creating the device of the screen type it is supposed that the shaded element (or their system) together with glazing forms an integrated construction with the known beforehand coefficients of heat transmission, heat absorption and heat reflection of every layer.

Heat input into the premises through the light aperture is made up of cut-through heat input of the direct and diffuse solar radiation q_1, heat input conditioned by absorption of the direct and diffuse radiation of the window construction q_2 and heat input as a result of difference in the temperatures of the external and internal air $q_{\Delta t}$.

$$q = q_1 + q_2 + q_{\Delta t} \tag{7.38}$$

The components of the total heat input differ on their character of influence on the heat regime of the premises and shall be determined separately. The flows q_2 and $q_{\Delta t}$ enter to the premises directly from the internal surface of the construction of the light opening. The through heat flow q_1 enters onto the internal surfaces of the enclosure and enters into the premises for the second time after partial absorption (25-50%) depending on the material of the surface.

Let's introduce the coefficient of the through K_{1S} and absorbed K_{2S} heat input of the solar radiation for comfort (*tables 7.9 and 7.10*). Then, the through heat input q_1 will be calculated according to the following formula:

$$q_1 = K_{1s}(I_s\tau_{rad} + I_d) \tag{7.39}$$

And the absorbed heat input q_2 will be calculated according to the following formula:

$$q_2 = K_{2s}(I_s\tau_{rad} + I_d) \tag{7.40}$$

where I_s and I_d are the design values of the straight (direct) and diffuse solar radiation for the surfaces of different orientation accepted according to the existing regulation, τ_{rad}-radiation coefficient of the light opening calculated according to [31].

Heat input to the premises is calculated by the following formula as a result of the difference the external and internal air temperatures:

$$q_{\Delta t} = \frac{t_o - t_a}{R_0} \quad (7.41)$$

where t_H– the design temperature of the external air, °C; t – air temperature in the premises, °C accepted according to the hygienic norms and or calculated from the equation of thermal balance for non-conditioned buildings; R_0 – resistance of heat conduction of the construction determined according to the related regulations.

Solving the system of equations of the heat transmission for the construction consisting of three elements, we obtain two main features of the heat input through the light opening with the screening solar control (picture 7.2).

$$K_{1s} = T_3 T_2 T_1 (1 + \rho_3 \rho_2^2 + \rho_3 \rho_2 + \rho_2 \rho_1) \quad (7.42)$$

$$K_{2s} = \frac{1}{R_0} [T_3 T_2 T_1 (1 + \rho_3 \rho_2^2 + \rho_3 \rho_2 + \rho_2 \rho_1)(R_o + U_3 R_2 + U_2 + R_1 + 0{,}5U_1) + T_3 a_2 (1 + \rho_3 \rho_2 T_2 + \rho_3 \rho_2 + T_2 \rho_1)(R_O + U_3 + R_2 + 0{,}5U_2) + a_3 (1 + \rho_3 T_2 \rho_2^2 + T_3 \rho_2)(R_o + 0{,}5U_3)] \quad (7.43)$$

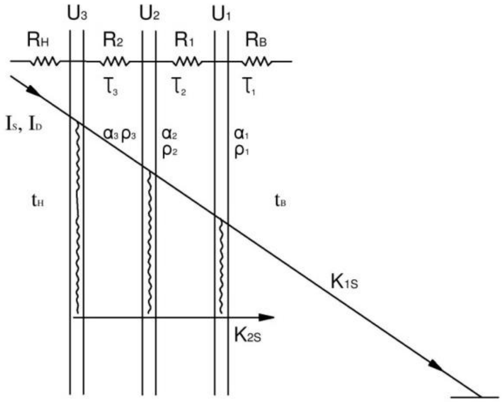
where τ_3 τ_2 τ_1 - the coefficient of heat transfer of different layers, α_3 α_2 α_1 – coefficient of heat absorption, ρ_3 ρ_2 ρ_1 – coefficient of heat reflection; U_3 U_2 U_1 – thermal resistance of the layers of the construction ($m^2 \cdot$ °C)/ W; R_H – resistance of the heat transmission of the external surface ($m^2 \cdot$ °C)/W; R_2, R_1 – thermal resistance of the air space ($m^2 \cdot$ °C)/ W.

The optic features of glasses and shaded elements depend on the angle of incidence of the solar beams that change within a day depending on the season of a year, width of the territory and the building orientation. Those values corresponding to the hours of a day with maximum intensity of solar radiation on July 16 for 40°C northern latitude and seven main orientations are admitted as the design values of the coefficients τ, α and ρ in formulas (7.42) - (7.43).

Coefficients τ^0_s and α_s^0 (see table 7.10) correspond to heat input and heat absorption of the window fillers of this type during normal angle of incidence of the solar beams. These features are certificated (passport data). They are determined by experienced ways and shall be known beforehand.

All air spaces were applied in the closed form in the provided calculation method. If the layers between the external solar protection and windows will be ventilated by the external air, the values of coefficients K_{1S}, K_{2S} will be less than given in table 7.10. The correction can be implemented during in – situ experiments of concrete samples.

Picture 7.2 A scheme for calculation of heat input through glazing



Introduction of coefficients K_{1S} and K_{2S} is also comfortable, because it allows to implement general estimation of the efficiency of the solar protecting devices till implementation of final calculation of the thermal conditions and the succeeding detailed analysis. The coefficient of the relative heat transmission of the solar protecting devices is included for estimation of the efficiency of solar control.

$$K_{sp} = \frac{K_{1s}+K_{2s}}{K'_{1s}+K'_{2s}} = K_s/K'_s \qquad (7.44)$$

where K'_{1S} and K'_{2S}-coefficients of the through and absorbed heat input of the solar radiation through the light opening without solar protecting device; K_s, K''_S – coefficient of the total heat input of the solar radiation through the light opening.

According to table 7.9,K'_S=0,76+0,05=0,81 for the windows with double glazing from usual glasses. K=0,11+0,14=0,25 for double glazing and external heat absorption of the glasses in black color (τ°_s=0.13; α=0.83) and the coefficient of the relative heat transmission K = 0.25 / 0.81 = 0.30

The analysis of obtained results shows that the efficiency of heat absorbing glasses corresponds to the internal solar control and solar control between the glasses made of tissues and venetian blind significantly abating to the external regulating devices.

The heat resistant glasses are applied purposefully in the residential houses. In the municipal buildings, where it is necessary to establish optimal conditions besides limitation of heat input in the summer period, application of special types of glasses are justified.

It is recommended to control the coefficient of the relative light shading K_{c3} of the regulated light shading device (LSD) which shall not exceed following values during elaboration of new types, as well as estimation of the constructions accepted in the project: for external LSD (curtain, sun blinds, canvas blind) – 0,20; for LSD (curtain) between the glasses-0,4; for the internal LSD (curtain, drapery) – 0,55.

Analyzing the data from tables 7.9 and 7.10 we can come to an interesting conclusion. The external solar control device of the curtain – venetian blind type gives better characteristic during painting of plates in dark colors (reflection-0.2; K_s=0.13; K_{c3}=0.16) in comparison with white plates (reflection -0.8; K_s=0.18; K_{c3}=0.22). If to place the dark curtains in the space between the glasses or in the external side of the window, its characteristic (K_s = 0.36; K_c = 0.43) will be significantly worse than the construction with white curtains-blinds (K_s = 0.26; K_c = 0.32).

Table 7.9 Coefficients K_{1S} and K_{2S} for windows with ordinary and heat resistant glazing

Construction of the window filler	**K_{1S} during orientation of light opening**			**K_{2S}**
	NE, NW, E, W	SE. SW	S	
Single glazing, Ordinary glasses:				
$\delta = 5\ mm;\ \tau_s^0 = 0{,}81$ $\alpha_s^0 = 0{,}1$	0,81	0,74	0,59	0,04
$\delta_0 = 15\ mm; \tau_s^0 = 0{,}66$ $\alpha_s^0 = 0{,}26$	0,66	0,57	0,45	0,09
$\delta_0 = 30\ mm; \tau_s^0 = 0{,}49$ $\alpha_s^0 = 0{,}44$	0,49	0,42	0,32	0,15
Heat absorbing glasses $\delta = 6{,}5\ mm;\ \tau_s^0 = 0{,}48$ $\alpha_s^0 = 0{,}52$	0,43	0,38	0,3	0,17
Double glazing Ordinary domestic glasses				
$\delta_0 = 2-3\ mm; \tau_s^0 = 0{,}87$ $\alpha_s^0 = 0{,}05$	0,76	0,65	0,48	0,05
$\delta = 5\ mm;\ \tau_s^0 = 0{,}81$ $\alpha_s^0 = 0{,}1$	0,65	0,55	0,38	0,07
External heat absorbing glasses, light $\delta = 65\ mm;\ \tau_s^0 = 0{,}62$ $\alpha_s^0 = 0{,}81$	0,5	0,41	0,26	0,09
Internal – ordinary; glasses, average lightness $\delta = 6{,}5\ mm;\ \tau_s^0 = 0{,}47$ $\alpha_s^0 = 0{,}47$	0,38	0,29	0,19	0,11

Internal – ordinary External – heat reflecting Domestic production $\delta = 6{,}5\ mm;\ \tau_s^0 = 0{,}13$ $\alpha_s^0 = 0{,}83$	0,11	0,09	0,06	0,14
Internal – ordinary External – heat reflecting $\tau_s^0 = 0{,}6$ $\alpha_s^0 = 0{,}12$	-	-	-	-
Internal – ordinary $\delta = 0{,}5\ mm;\ \tau_s^0 = 0{,}29$ $\alpha_s^0 = 0{,}53$ Inner-usual	0,54 0,24	0,44 0,20	0,3 0,13	0,07 0,15

Table 7.10 Coefficients K_{1S} and K_{2S} for windows with sun protection

Construction of the window filler, the type of protection	Location of the shielding elements (1-internal; 2-between glass panes; 3-external)	Orientation of the light opening					
		NE, NW	E, W	SE		SW	S
		K_{1s}	K_{2s}	K_{1s}	K_{2s}	K_{1s}	K_{2s}
Double glazing, sun protection from fabric:							
Cotton, dense, dark green color ($\tau_s^0 = 0.005; \alpha^0_s = 0.84$)	1 2 3	0,04 0,04 0,04	0,47 0,31 0,11	0,02 0,02 0,03	0,42 0,29 0,1	0,01 0,01 0,01	0,32 0,25 0,1
Fiberglass, dense, grey ($\tau_s^0 = 0.15; \alpha^0_s = 0.43$)	1 2 3	0,13 0,13 0,13	0,28 0,18 0,06	0,09 0,09 0,09	0,23 0,16 0,06	0,06 0,06 0,06	0,18 0,14 0,06
Fiberglass, semitransparent, white ($\tau_s^0 = 0.35; \alpha^0_s = 0.10$)	1 2 3	0,29 0,29 0,29	0,09 0,06 0,03	0,2 0,2 0,2	0,1 0,07 0,03	0,1 0,1 0,1	0,1 0,07 0,03
Fiberglass, transparent, white ($\tau_s^0 = 0.54; \alpha^0_s = 0.05$)	1 2 3	0,43 0,43 0,43	0,07 0,05 0,04	0,29 0,29 0,29	0,13 0,10 0,05	0,14 0,14 0,14	0,13 0,1 0,05
Double glazing, sun protection by curtain blinds:							
Straightening under angle 45°, dark color (reflection coefficient – 0.2)	1 2 3	0,02 0,02 0,02	0,50 0,33 0,11	0,02 0,02 0,02	0,50 0,33 0,11	0,01 0,01 0,01	0,32 0,25 0,1
The same, light color (reflection coefficient – 0.4)	1 2 3	0,04 0,04 0,04	0,41 0,27 0,09	0,04 0,04 0,04	0,41 0,27 0,09	0,01 0,01 0,01	0,027 0,21 0,08
The same, white color (reflection coefficient – 0.8)	1 2 3	0,13 0,13 0,13	0,2 0,13 0,05	0,13 0,13 0,13	0,2 0,13 0,05	0,06 0,06 0,06	0,14 0,11 0,04

The results of the researches of the heat and solar control features of windows in the southern regions allow to conclude:

1. *The solar protecting constructions shall be designed with the geometrical dimensions totally excluding the passage of the direct solar beams through windows within all exploitation period of the premises in hot time of year if shading by stationary means of solar control from the constructive con siderations or from the conditions of natural illumination is not possible within all period of insolation of the enclosure and additional use of the internal curtains is necessary.*
2. *Sunshields are ineffective means for solar protection of building in the southern regions and don't have special architectural qualities. It is preferable to apply*

the solar protecting means of the venetian blind type or cellular solar control constructions with heat conduction 12-20%. These means allow to reduce temperature significantly: internal surface of glazing-for 10ºC, internal air of the premises (for more unfavorable conditions) with the window of the western orientation – for 6 ºC and radiation temperature for 13 ºC.

3. *Large solar protecting constructions made of reinforced concrete may be effective under condition of removing them from the shielded barriers for 40-45 cm , and the construction made of aluminum, polymers and other materials – for 30 cm.*
4. *The through ventilation of unconditioned premises during the evening, night and morning hours, as well as short-term (15-20 minute) day ventilation significantly increases sanitary-hygienic conditions in the premises at the absence of the light opening insolation.*
5. *Application of solar protecting constructions with low heat capacity on the facades of the building oriented to the east and south east is preferable. Such kind of constructions gives accumulated heat within small interval after cessation of insolation of facades and takes the temperature of the environ ment without putting additional load on the premises during its short – term day ventilation.*
6. *The solar control devices under which the temperature of the internal surface of usual glazing doesn't exceed 34ºC within the period of maximum thermal effects are efficient enough for heat resistance of glasses. This value shall be normalized for the construction – climatic regions of Central Asia.*

As it was mentioned, designing of the solar control means is associated with selection of constructions depending on the orientation of enclosures and their geometrical calculations. Stationary solar control constructions may be very effective from the functional point of view during proper selection and calculation. Substantively, horizontal, vertical elements or their combination are its functioning elements not depending on the configuration of the solar protecting devices (table 7.11). Sunblind (with different angles of slope α) and sunshields may be considered as varieties of cellular constructions (combination of vertical and horizontal elements). The diagram given in table 7.3 was drawn on the basis of the analysis peculiar for the geographical latitudes of Central Asia, angle of incidence of the solar beams on the vertical enclosures and as well as the results of the insolation calculations [32]. The Sun coordinates corresponding to the following calculation data were taken into account: June 22 - for vertical elements of the sunscreens; August 22 – for horizontal and cellular constructions. Calculation according to the mentioned data provides complete shading of light openings: in the horizontal position – in the period from April 22 to August 22, in the vertical position – in the course of year. The latter allows to conclude that the application of vertical unregulated edges for the solar protection of the premises related to the terms of visual works of the highest ranks, as according to the data of researches the coefficients of light transmittance have lower values in the points far from the windows in overcast weather. These constructions may be used only in the municipal buildings where insolation of the premises is not a comfort element during winter period.

Minimal rise of the elements of sunscreen of any configuration providing effective shading of opening is obtained by choosing the position of the elements of the shading construction in windows in accordance with the instructions (see picture 7.3) completed by the geometrical calculation.

The geometrical calculation for regulated constructions has no meaning. It is only necessary to keep in mind that they shall be designed in such a way that individual elements could be completely closed up forming entire light transmission screen. In this case, the width of individual elements of sunblind shall be taken as equal to the distance between them or shall exceed it slightly in order elements to overlap one another when turning.

The dimensions of the stationary sunscreens can be determined by both analytical and graphical ways. The general shortage of these applications is associated with the necessity of preliminary implementation of a range of auxiliary operations complicating the designing process of the shading devices. Apparently, just this position leads to improper selection and irrational decision of the stationary solar protecting constructions in the building.

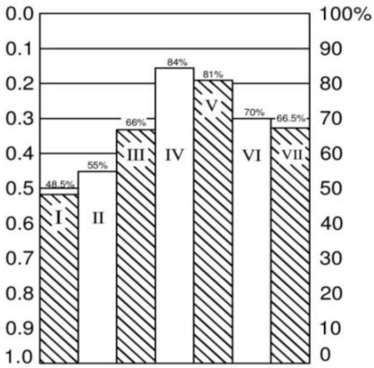
Design calculations are given for rising the elements of the shading means through the auxiliary data calculated and tabulated beforehand for all orien tations and latitudes of regions within 36 – 44 ° covering practically all the Central Asia territory. The recommended calculation in table 7.11 allows to determine geometrical dimensions of the sunscreen elements by express method providing complete shading of the light opening within the period of its insolation.

Table 7.11 Coefficients for determination of the geometrical dimensions of the sunscreen elements

Orientation of protections	Φ, grad	36 ° n.l.		40 ° n.l.		44 ° n.l.		Shading elements of solar protection	Calculated ratio
		K_h	K_v	K_h	K_v	K_h	K_v		
N – NE N – NW	0	-	1,19	-	1,17	-	1,15	-	-
	15	-	0,94	-	0,92	-	0,91	-	-
	30	-	0,81	-	0,8	-	0,79	-	-
	45	-	0,77	-	0,76	-	0,75	-	
N E	0	-	3,27	-	3,08	-	2,9	Vertical	$V=aK_v$
N W	15	-	1,81	-	1,74	-	1,69	”	”
	30	-	1,305	-	1,28	-	1,25	”	”
	45	-	1,08	-	1,07	-	1,05	”	”
E NE W NW	0	-	11,4/2,75	-	9,5/2,61	-	8,14/2,48	-	-
	15	-	2,9/1,65	-	2,7/1,59	-	2,66/1,54	-	-
	30	-	1,74/1,23	-	1,69/1,21	-	1,65/1,18	-	-
	45	-	1,30/1,04	-	1,28/1,02	-	1,26/1,01	-	
E W	0	8,5/2,9	-	8,14/2,9	-	7,1/2,9	-	Horizontal	$a=hK_h$
	15	2,69/1,69	-	2,66/1,69	-	2,53/1,69	-		”
	30	1,66/1,25	-	1,65/1,25	-	1,61/1,25	-	”	”
	45	1,27/1,05	-	1,26/1,05	-	1,25/1,05	-	”	
E SE W SW	0	2,61	2,36	2,64	2,48	2,75	2,61	Combination of vertical and horizontal (vertical elements are perpendicular to glazing)	$a=hK_h$ $v=aK_v$
	15	1,59	2,45	1,61	2,58	1,65	2,7		
	30	1,2	2,7	1,21	2,9	1,23	3		
	45	1,02	3,23	1,03	3,5	1,05	3,7		
S – E S – W	0	1,38	1,38	1,43	1,48	1,48	1,6	Combination of vertical and horizontal (vertical elements are perpendicular to glazing)	
	15	1,04	1,43	1,08	1,53	1,1	1,65		
	30	0,835	1,6	0,91	1,7	0,92	1,85		
	45	0,82	1,92	0,83	2,09	0,87	2,27		
S – SE S – SW	0	0,9	0,625	0,93	0,65	1,036	0,727	Ditto	
	15	0,75	0,65	0,77	0,67	0,84	0,75	”	”
	30	0,685	0,72	0,7	0,745	0,75	0,84	”	”
	45	0,67	0,89	0,69	0,92	0,715	1,03	”	”
S	0	0,445	-	0,532	-	0,625	-	Horizontal	$a=hK_h$
	15	0,412	-	0,478	-	0,554	-	”	”
	30	0,408	-	0,47	-	0,530	-	”	”
	45	0,435	-	0,49	-	0,544	-		

Note: *a – width of the sunscreen elements; B – distance between the vertical sunscreen elements; h-distance between the horizontal sunscreen elements; Ψ-slope of angle of the horizontal element with respect to normal glazing*

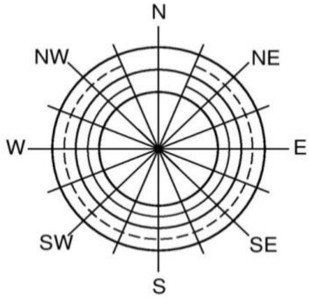
Pic. 7.3 Heatproof efficiency of the sunscreens



I, II – sunshields (corresponding to K_{c3} = 0,75 and 0,5); III – marquees (light colored, α = 30°); IV – VII – sunblinds (corresponding to K_{c3} = 0.8 and α = 45 °; K_{c3} = 0.35 and α = 45 °; K_{c3} = 0.35 and α = 30 °; K_{c3} = 0.35 and α = 0 °).

The calculation principle is as the following: the necessary altitude of elements *a* is determined through auxiliary data (see table 7.11) in the given distance between the sunscreen elements. We obtain the geometrical dimensions of elements not hindering the transition of direct solar beams only during the last hour of the insolation of enclosure while using the coefficients in the calculated ratios provided in the denominator. It is recommended to use these coefficients in the cases when provision of complete shading of light openings worsens the conditions of natural illumination of the premises or it is not possible due to the constructive conditions. Optimal slope of angle of the elements of sunscreens may be chosen from the point of view of minimal material expenditures for construction through analysis of the data presented in table 7.11. In this case, the results of the researches of Ya. D. Shvets showing that the horizontal sunblinds having the slope of angle towards the horizon from 0 to 30º are characterized by the best light scattering indexes should be taken into account [33].

Pic. 7.4 The area of application of the stationary sunscreen elements on the sides of horizon



–horizontal; ----- – horizontal and vertical; . –vertical

Recommendations on the field of application of the stationary sunscreen elements (picture 7.4) are not limited rigidly. Any of the mentioned constructions may be also used on the facades of other orientations when properly calculated and substantiated by appropriate way. But, it is necessary to take into account that it will be suboptimal and consequently, less economical version. The mentioned boundaries indicate the area of preferred application within inside of which the recommended types provide effective shading at optimal removal of the construction elements.

It is necessary to take into account that the elements of the device shall be prolonged in both sides from the window openings to the length equal to the distance between the elements of the shading means for provision of complete shading of the light opening in design period.

The architects try to use architectural and artistic merits of sunscreens as much as possible enriching the plastic solution of the facades of the buildings during construction of buildings in the southern regions. Care about aesthetics of the exterior of buildings is necessary and has great value. But, in this case it is necessary to take into account that the meeting of heat engineering, light and other requirements is the primary task. Excessive increase of the construction by decorative elements leads to ineffective choice from a functional point of view and economically unsubstantiated versions of solar protection.

7.6. Indoor air balance

Air filtration through the enclosing constructions is assessed for both determination of the building's heat losses and taking them into account in the air balance equation of premises and buildings as a whole.

The quantity of air G, kg/(m^2·hour) entered to or leaving through inclosing constructions is determined according to the following formula:

$$\frac{G=(|\Delta P|)^{n}1}{R_i} \tag{7.45}$$

where ΔP-difference of tension on the outside and inside surfaces of enclosing construction, Pa; R_i-the resistance of air permeability of the enclosing construction, m^2·hour·Pa/kg; n=1 for the external enclosing constructions (except the fillers of the light openings) and n=2/3 for the fillers of the light openings.

The values of the air permeability resistance of the light opening fillers (windows, balcony doors and lanterns) as well as materials and constructions are provided in the relevant regulations [34]. These values correspond to 18 °C air temperature. For other temperatures, the air permeability resistance is calculated by the following formula:

$$R_t = R_{18}\sqrt{\gamma_{18/}\gamma_t} \tag{7.46}$$

where the index 18 means that the given parameters are used at the temperature equal to18 °C; index *t* means other temperature.

As a result of the wind influence a pressure differing from the atmosphere pressure occurs inside the building. The difference between this pressure and atmosphere pressure is called as excessive internal pressure P_x. The value of P_x may be both positive and negative. The external pressure influencing the building is equal to:

$$P'_n = P_a - h_n\gamma_n + \frac{k_n V_n^2}{2g\gamma_o} \tag{7.47}$$

where P'_n – the external pressure at the central level of n^{th} "aperture", Pa; P_a – atmosphere pressure on the conventional reference (counted) level which is admitted at the earth level, Pa; h-the distance of the centre of n^{th} "aperture" from the conventional reference level, m; k_n – aerodynamic coefficient in the plane of n^{th} "aperture".

The air pressure inside the building is:

$$P'_n = P_a + P_x - h_n\gamma_a \tag{7.48}$$

where P'_n-the internal pressure at the central level of n^{th} "aperture", Pa; P_x-excessive internal pressure in the premises on the conditional level of counting, Pa.

Proceeding from (7.47) and (7.48), we will find the expression for determination of the air tension difference on the outside and inside surfaces of the enclosing constructions of building.

$$\Delta P = |P'_n - P''_n| = \left| |-h_n(|\gamma_e - \gamma_i) + k_n \frac{V_e^2}{2g}\gamma_e - P_x \right| \tag{7.49}$$

where γ_e and γ_i are the specific weight corresponding to the outside and inside air, H/m^3.

$$\gamma = 9{,}81 \cdot 353/(273 + t)$$

where t – is the air temperature corresponding to the outside and inside air for determination of γ_i and γ_e, respectively.

Further, it is more comfortable to consider conditionally internal excessive pressure P_x as constant value and the calculating internal pressure as:

$$P_n = -h_n(\gamma_o - \gamma_a) + k_n V^2/2g\gamma_o \tag{7.50}$$

We will call the excessive pressure P_x as the internal pressure for simplicity. Taking it into account, we can express the formula in the following form:

$$\Delta P = |P_n - P_x| \tag{7.51}$$

where P_n is determined according to (7.50).

The equation of the air balance of the building has the following form:

$$\sum_i G_i + \sum_l G_l = 0 \tag{7.52}$$

where G_i-the air volume through the enclosing construction; G_l-the air volume directly transmitted to the premises or removed from it.

We receive the balance equation for determination of P_x by putting the expression for air flow through the enclosing constructions determined by the pressure difference in the last equation. Solving this equation and finding P_x it is possible to calculate air flow through the enclosing constructions and the heat lost related with it by formula (7.45).

The intensity of natural air exchange is determined by availability of the wind and thermal head, i.e. it depends on the speed and direction of wind, geometrical dimensions, indoor structures design and difference between the outside and inside temperature. A great number of the works has been devoted to the qualitative and quantitative assessment of indoor air exchange [35-38]. According to the results of the observations on residential houses it can be concluded that only single change of air per an hour can be calculated when the doors and windows are closed and there is weak wind; the multiplicity of air exchange may be increased to 2 when the wind speed increases up to 4 m/sec. Opening of doors and windows can cause the increase of ventilation speed up to 10-30 exchanges per hour. The results derived from the researches carried out under various wind speeds (0-3,5m/sec) and directions, and also different orientations of windows and ventilation devices have shown that the values of multiple air exchange in the premises varied from 0,3 to 4 exchanges per hour. Existing types of exploitation regimes in summer conditions are considered uninterruptedly within a day or night ventilation of the premises to increase air mobility during the daytime and for effective cooling of the premises at night. Proper quantitative and qualitative assessment of air exchange is necessary for calculation and analysis of the heat regime within a day [39].

It is possible to recommend the use of forced ventilation and aggregates of the evaporative cooling as effective and comparatively cheaper means of artificial climate improving.

It was established that the exploitation of the air conditioning and radiation cooling systems will be efficient together with active ventilation at night time in the regions with big daily temperature fluctuations.

7.7. Heat transfer through external enclosures

Heat input through coating and walls is calculated basing on the following suppositions:

a) *Temperature field in the enclosure is univariete.*

b) *Heat source is absent inside the enclosure.*

c) *The thermal characteristic of multi-layer enclosures doesn't depend on the temperature and is constant within one layer.*

$$c(y)\rho(y)\frac{\partial t}{\partial T} = \frac{\partial}{\partial t}\left[\lambda(y)\frac{\partial t}{\partial y}\right] \ (0 < y < \delta) \tag{7.53}$$

$$\text{where } c(y)\rho(y), \lambda(y) = \left\{\begin{matrix} c_1\rho_1, \lambda_1 \text{ at } 0 \le y \le \delta_1 \\ c_2\rho_2, \lambda_2 \text{ at } \delta_1 \le y \le \delta_2 \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots \\ c_{n-1}\rho_{n-1}, \lambda_{n-1} \text{ at } \delta_{n-2} < y \le \delta_{n-1} \\ c_n\rho_n, \lambda_n \text{ at } \delta_{n-1} < y \le \delta_n = \delta_1 \end{matrix}\right\} \tag{7.54}$$

where c_i, p_i, λ_i – specific heat capacity, W·hour / (kg · °C); density, kg/m^3 and coefficient of heat conduction of the material of ith layer of the enclosure, W/

(m^2·°C) (i=1,2..., n), respectively; c_i, p_i,-voluminous heat capacity of the material of i^{th} layer of the enclosure, W· hour / (m^3 · °C).

The boundary conditions for equation (7.53) are the equation of the heat balance on the external and internal surfaces of the enclosure. The heat balance of the external surface of the enclosure is formed of heat input from the solar radiation q_{sol}, convective heat flow between the surfaces and air washing it $q^H{}_c$, radiant heat flow between the surface and the environment $q^H{}_r$; amount of heat passed or taken through the heat conduction from the surface inside the enclosure q_H.

Heat input from the solar radiation is determined by the following formula:

$$q_{sun} = \rho I(T) \tag{7.55}$$

where ρ-the coefficient of absorption of the total solar radiation flow by the external surface of enclosure (depending on the material of the surface of inclosure); l(τ)-intensity of the total solar radiation flow fallen on the surface of the inclosure (depending on the width of the territory, orientation of the enclosure and hours of day), W/m^2.

The value of the coefficient ρ is given in the work [40].The values of intensity of the solar radiation flow l(τ) depending on the orientation for July are provided in accordance with the related regulation.

The convective heat flow between the external surface of the enclosure and the air washing it is determined according to Newton formula:

$$q_k^o = a_k^o[t(0,T) - t_o(T)] \tag{7.56}$$

where $\alpha^H{}_c$-is the coefficient of the convective heat exchange, W/(m^2·°C); t(o, τ) -temperature of the external surface of enclosure, °C; t_H(τ)-temperature of the external air °C.

Not only the solar radiation and the temperature of the external air, but also temperature of the environment also influences the external surface of enclosure.The heat flow between the surface and the environment is determined according to the following formula:

$$q_l^o = a_l^o[t(0,T) - t_{sur}(T)] \tag{7.57}$$

where $a^o{}_l$ -the coefficient of heat exchange between the surface and the environment, W/(m^2 · °C); t_{sur}(T) – temperature of the environment, °C.

The equation of the heat balance of the external surface will have the following form:

$$y = 0 - \lambda \frac{\partial t}{\partial y} = a_k^o[t - t_o(T)] + a_l^o[t - t_{sur}(T)] - \rho I(T) = (a_k^o + a_l^o)\left[t - \frac{a_k^o t_o(T) + a_l^o t_{sun}(T)}{a_k^o + a_l^o}\right] - \rho I(T) \qquad (7.58)$$

$$a_k^o + a_l^o = a_o$$

The following equation is used in the engineering calculations not requiring special exactness:

$$\frac{[a_k^o t_o(T) + a_l^o t_{sur}(T)]}{a_k^o + a_l^o} = t_o(T) \qquad (7.59)$$

The heat balance of the internal surface of enclosure is made of convective thermal flow between this surface and air of the premises q^B_c, radiant heat flow between this and surrounding surfaces q^B_r and the amount of the heat passed to the surface or taken from it by the heat conduction q:

$$y = \delta - \lambda \frac{\partial t}{\partial y} = q_k^a + q_l^a = a_k^a[t - t_a(T)] + \sum C_0 \in_{i-j} (t_i - t_j)\varphi_{i-j} = a_a^{con}(t - t_a^{con}) \qquad (7.60)$$

$$a_a^{con} = a_k^a + \sum C_0 \in_{i-j} b_{i-j}\varphi_{i-j} \qquad (7.61)$$

$$t_a^{con} = -\frac{1}{a_a^{usl}}[a_k^a t_a(T) + \sum C_0 \in_{i-j} b_{i-j}\varphi_{i-j} t_j$$

where α^B_c – the coefficient of the convective heat exchange on the internal surface, W/(m^2·°C); $t_B(\tau)$ -temperature of the internal air, °C;C_0-coefficient of radiation of absolute black body, C_0=4.96 W/ (m^2 · K^4); ε_{i-j} -reduced factor of radiation of ith and jth surface, φ_{i-j}-coefficient of radiation from the ith surface to the jth surface; b_{i-j}-temperature coefficient [28]; t_j-temperature of jth surface; °C.

The external surfaces of the enclosure are subject to the influence of direct and diffuse solar radiation. The solar beams reflected from the molecules, from availability of grains and water vapors in air, from the earth surface and also from trees, buildings and finally from blocks give scattered (diffuse) solar beams. The intensity of irradiation of one or another surface by diffuse solar beams depends on the environment that "sees" the surface. Its value will be maximum for horizontal surface that "sees" the firmament, and minimum – for vertical surface. The intensity of the diffuse radiation is significantly enough and shall be taken into account especially during calculation of the inertialless enclosures to which windows belong.

The temperature of the outside air and solar radiation has explicit periodic character within a day during several summer months in the southern regions. The daily course of these influences is permanently used within long – lasting period, so, it is possible to neglect the initial distribution of temperature and consider so called quasi stationary or stationary-periodic process presenting external thermal effects in the form of the sum of members of harmonic series.

The building is the single heat inertial system which decreases the temperature fluctuation of the external environment. In – situ observations show that the fluctuation of temperature inside the premises is significantly less than the external temperature and it is always late for some hours with respect to external thermal affects. When the temperature of the external air increases and external surfaces of enclosures are irradiated, the heat flow is directed to the constructions' thickness which accumulates a part of this heat. Remaining part reaches the internal surface with significant delay with respect to the external surface wherefrom transferred by convection to the air of the premises and by radiation to other enclosures and objects.

The heat flow changes its direction to the opposite direction when the temperature of the external environment decreases. The cooling process begins from this moment: heat is given to the environment by convection and radiation. Heat emission from the construction to the internal air continues if its temperature becomes lower than the temperature of the internal surface. It happens for example, in the cases when the premise becomes cold due to the night air. Thereby, the inertial features of the building decrease overheating of the premises in daylight hours, and prevent their cooling at night when the temperature of the external air decreases.

The resistance of the construction and premises against penetration of external heat waves is called as thermal stability. The latter determines the capacity of materials, constructions and premises to resist against temperature variations and is characterized by the values of attenuation and delay of oscillation phases. Attenuation is usually expressed as the ratio of amplitude of influence fluctuation to the amplitude of fluctuation of the fixed temperature taken for corresponding harmony. The delay of phase is the backlog of fluctuations of the determined magnitude from external influences expressed in hours or degrees.

The thermal resistance and the daily course of the internal temperature associated with it in the premises where the temperature of internal air is not stable depends on the character and values of the internal influences, operating conditions, thermo-physical properties of the external and internal enclosures, the ratio of their areas and heat exchange conditions on the surfaces.

Notwithstanding that specific heat amount passing to the premises through nontransparent areas of the external enclosures is not more than heat passed through windows and ventilation air, general heat conduction through them may play an important role in the formation of internal temperature.

The walls and covers irradiated by the Sun may be heated to 60-70 and 70 – 89 ^oC, accordingly and the decrease of the coefficient of solar beams absorption through painting surfaces in light colors or using corresponding materials will be the most effective measure related to solar protection.

Maximum air temperature in the houses built of hollow bricks with whitened walls of 28cm thickness was 3,5^oC lower than the temperature of the concrete wall. On the internal surfaces of all brick walls with 11 cm thickness painted in white color the temperature was 3-6^oC lower than the temperature of unpainted walls. On the other hand, the solar beams reflected on white surfaces of the wall fall on the walls of other buildings and surrounding landscape causing undesirable blindness. Quick increase of the coefficient of absorption due to the dustiness of the surface should be attributed to shortcomings of this solar protection method.

Despite the fact that the constructive measures on solar protection of walls and coatings increase the cost of protection in some cases, they are more effective compared to other applications. The use of constructions with air spaces in combination with reflecting heat isolation seems rational. The results of researches on the heat resistance of light wall panels showed that thermal insulation features of the wall construction reinforced by foils of air spaces in the thickness 6 cm are not worse compared to the usual concrete wall with 25 cm thickness [41].

Water roofing, using the effect of decrease of the solar radiation effect by means of water evaporation allows to decrease the thickness of heat insulation material. Heat emission through the water roofing decreases to 65% in comparison with dry roofing of the same construction. The heat flow dec reases even more during dispersion of water on the roofing surface through special sprinkler devices.

The positive role of roofing on basements or floors located directly on the ground is very essential.

Thermal insulation features of each external enclosure are determined by thermo-physical parameters of construction materials. The formation of average temperature in the premises is associated with thermal resistance of the construction: the larger it is, the larger is difference between the external and internal temperatures.

If heat input exceeds the exploitational heat emissions, the increase in the heat resistance of enclosures plays a positive role and vice – versa. The heat resistance of materials is characterized by its coefficient of temperature conduction being the measure of temperature intensity variation on the construction thickness during non-stationary processes of heat transmission. The smaller the temperature conduction coefficient the more heat is accumulated in the construction thickness during the temperature change and more heat waves attenuate.

Researches on the thermo-physical features of the construction materials in the wider range showed that very light materials such as styrofoam (foamed polystyrene) (ρ=15-35 kg/m^3) are good heat isolating materials during assessment of their thermal resistance, i.e., for heat protection in winter conditions under high coefficient of temperature conductivity. However, this limits their use under the large daily fluctuations of summer temperature. The materials with 150-900 kg/m^3 density such as glass fiber and light concrete are more effective. In this range of density, first of all the coefficient of temperature conductivity sharply decreases, then it remains nearly constant and the coefficient of heat conduction slightly increases. Both coefficients increase and their heat conduction feature becomes worse at bigger densities.

The indicator of thermal inertia D which is determined as production of heat resistance R against the coefficient of heat absorption S serves as the attenuation character of the heat waves in the thickness of uniform enclosure:

$$D = RS = \frac{l}{\lambda\sqrt{\lambda c\gamma\omega}} = l\sqrt{\omega/a}$$

The greater the value of the index of thermal inertia, i.e. the more massive enclosure, the higher temperature fluctuation will be in the premises under other equal conditions.

At daytime, we are interested in the increase of heat resistance in order to decrease the internal temperature during overheating hours, but it is significantly difficult to cool the premises with heat resistant enclosures after decrease of the outside air temperature. It would be desirable to decrease the heat resistance at night.

7.8. Method of calculation of non-stationary heat climate in buildings

The calculation method shall meet the following requirements:

a) *Preciseness and clarity of drawing of the design scheme;*
b) *Reliability of implementation of calculations in the range of possible variations of the initial parameters;*

c) Accuracy of the results derived from calculations;

d) Possibility of comparatively simple introduction of changes in the design formula during calculation of additional factors;

The method of calculation based on the use of computers meets these requirements more fully. On one hand wide application of computers allow to automate labor intensive method of calculation, on the other hand to establish solution with less number of simplifying assumptions, to expand signi ficantly the scope of use of solutions and to increase the accuracy of calculation results. It is especially important that finally a single program enabling calculation of thermal regime of the premises both in summer and winter conditions can be developed taking into account economic expediency of the constructive solutions and the capacity of the thermal regime regulation system. The principle of development of such kind of program is based on the use of solution of generalized equations [26].

Analytical, numerical and analytic-numerical task solution methods may be used for programming. Unconditionally, the analytical solution is privileged for this purpose. Due to the fact that at present the analytical solution of the indoor temperature regime calculation task poses serious mathematical diffi culties, the combination of numerical and analytical solutions is more expedient.

The net method which is based on replacement of derivatives with their approximate values expressed by difference of values of the functions in separate discrete points-mesh nodes is better elaborated and effective method of solution of heat conduction equations by computers. Special schemes were developed for straight calculations without using information on position of the explosion points for solution of the heat conduction equations with explosive coefficient to which the equations describing the temperature regime of multi-layer construction [42]. These schemes have been recognized world wide. Thus, there have been scientific and technical possibilities to develop a method of the indoor temperature regime calculation using computers up to the present time.

Let's first consider utilization of the grid method (finite difference method) to obtain the solution of the equation:

$$c(y)\gamma(y)\frac{\partial t}{\partial T}=\frac{\partial}{\partial y}\left[\lambda(y)\frac{\partial t}{\partial y}\right]\ (0<y<\delta) \tag{7.62}$$

$$y=0\ \lambda\frac{\partial t}{\partial y}=a_o(t-t_o)-\rho I(T) \tag{7.63}$$

$$y=0\ \lambda\frac{\partial t}{\partial y}=a_a^{con}(t-t_a^{con})+q_l(T) \tag{7.64}$$

While solving the equation (7.62) with the boundary conditions of (7.63), (7.64) we will suppose that we know the values of t_a^{con} at every moment of time. We use the balance method (integro-interpolation method) for solution [42].

The difference grid $\omega\Delta h,\Delta r$ = {y_i= Σ Δh_k, k= 0, 1, 2…M}x {r_i= ΣΔr; j = 0, 1, 2…, j_k} is introduced in the field Q_T = {0 ≤ y≤ δ ; 0≤ T ≤ T_{end}}. Inside the cut [o, δ] the grid is uneven, but inside each cut [δ_i, δ_{i+1}] is even with steps equal to Δh_i. Inside the cut [o, j_k] the grid is even with steps equal to Δτ.

As a result of algorithm for solution of equation (7.62) with the boundary conditions of (7.63), (7.64) has the following sequence:

1. *Coefficients are calculated:*

$$d_{i+1} = \frac{2\lambda_{i-1}\lambda_i}{\Delta h_i(\lambda_{i-1+}\lambda_i)} \text{ at } i = 1,2,\dots\dots\dots, M \tag{7.65}$$

$$s_i = \frac{2\Delta T}{G_i\Delta h_i + G_{i+1}\Delta h_{i+1}}$$

at i=1,2,…….,M-1

$$A_i = s_i, d_i;\ B_i = s_i d_{i+1};\ C_i = A_i + B_i + 1$$

2. *j = j is appropriated.*
3. *The values $t_H(\tau)$, I (τ), t_a^{con} (τ) are calculated for the given moment of time.*
4. *Running coefficients are calculated (direct run):*

$$a_1 = (a_o + \frac{\lambda_1}{\Delta h_1})^{-1}\frac{\lambda_1}{\Delta h_1};\ \beta_1 = a_o(a_o + \frac{\lambda_1}{\Delta h_1})^{-1}\ [t_o(j\Delta r) + \frac{\rho I(j\Delta r)}{a_o}];$$

$$a_{i+1} = \frac{B_i}{a_i - a_i A_i};\ \beta_{i+1} = (A_i\beta_i + t_{i,j=1})/(a_i - A_i a_i) \tag{7.66}$$

at i=1,2,…..,M-1

5. *The value of temperature on the internal surface (y = δ) is calculated*

$$t_{M,j} = \frac{t_a^{con} + \frac{\lambda\beta_M}{\Delta h_M}}{a_a^{con} + \frac{\lambda_M}{\Delta h}} \tag{7.67}$$

6. *The field of temperature for i=M-1, M-2, ….1 (backward run) is calculated:*

$$t_{i,j} = a_{i+1}t_{i+1}, j + \beta_{i+1} \tag{7.68}$$

7. *Let's pass to the calculation of field of temperature on (j +1) times.*

Calculation continues until the value t_i doesn't begin to be repeated periodically.

The value of the temperature of the internal air and value of temperature of the internal surfaces of other enclosures is accepted at j-1 provisional step during solution of the equation of heat conduction of the enclosure at j^{th} provisional step.

Then, we solve the equation of the heat balance of the internal air admitting the value t_B at j-1 provisional step. Finally, we solve the equation at j^{th} provisional step accepting the value of the internal surface at j-1 provisional step.

We again begin to solve equation (7.62) at j^{th} provisional step taking it as air temperature and temperature of the internal air which was calculated at the given step until the following condition is implemented:

$$\left|t_{a,j}^{s+1} - t_{a,j}^{s}\right| \leq \epsilon_1; \left|t_j^{s+1} - t_j^{s}\right| \leq \epsilon_{2\,\left|t_{a,ob}^{s+1} - t_{a,ob}^{s}\right| \leq \epsilon_3} \quad (7.69)$$

where $t_{B,j}^{S}$, t_j^{S}, $t_{job,}^{3}$ -temperatures of the internal air and internal surface of the enclosures at s^{th} provisional step in j^{th} iteration, respectively; $t_{B,j}^{S+1}$, t_j^{S+1}, $t_{job,}^{3+1}$ – ditto in s+1 iteration, ε_1, ε_2, ε_3 – accuracy values.

The following requirements were put while drawing up the algorithm and computer program:

1. *To choose the design diagram taking into account more complete balance of heat in the premises under non-stationary conditions;*
2. *To provide maximum performance of the program;*
3. *To allow subsequent completion of calculation scheme and relatively slight alteration in the program.*

7.9. Research of capabilities of providing comfortable indoor temperature conditions in summer period through construction tools

Overheating of the premises may be significantly decreased through the following measures: landscaping, planting and watering of the surrounding territory; solar protection of light opening and nontransparent areas of the external enclosures; provision of necessary heat resistance; intensive ventilation at night and rational planning of apartments. Thus, as the laboratory researches showed that the use of natural regulation means may decrease the temperature of the internal air only for 8-11ºC in arid regions compared to humid environ ment. When the temperature of the external air exceeds 34-35 ºC, as a rule these measures are not enough and discomfort conditions are determined in the premises requiring the use of artificial cooling systems.

At the present time, the air conditioning when the air processed and cooled according to the normative parameters is given to the premises is most radical way out of overheating.

Radiant panel cooling which is realized through circulation of chilled water on coils located on the wall and ceiling panels has long been an effective system of artificial regulation of climate. All other measures related to the improvement of internal conditions have secondary character and are directed to mitigation of unfavorable factors of the external environment. Some of them, for example sun screening of the buildings to this day retained their importance and will contribute to reducing the load on cooling systems during conditioning.

The heat of the sun beams entered to the premises through glazing is almost completely accumulated inside and is one of the reasons of overheating, especially under unfavorable orientation of windows. Solar controlling decreases the daily temperature to 0,8-2,5ºC, and maximally to 1,7-5ºC. At the present time, all issues associated with the calculation of solar radiation, efficiency of solar control under different orientations of light opening have been deeply and completely researched. The types and constructions of the solar protection devices application of which is recognized mandatory in the south regions have been developed.

The secondary factor influencing the formation of the indoor climate is heat exchange. It is necessary to distinguish the aeration of the premises to increase the air motion speed for improving people feeling (even if it leads to some increase of the inside temperature) from the intensive ventilation (desirably forced) for the purpose of cooling of the premises and construction by night air.

Two ventilation regimes are observed in summer conditions during buildings maintenance: night regime under which the premises is actively ventilated only at night time usually when the external temperature becomes lower than the internal temperature, and round-the-clock ventilation under which the ventilation is realized interruptedly within all days excluding some hours when the external temperature is maximum. As a rule, regime of the night time ventilation is used in the regions with hot and dry climate with big daily fluc tuation of temperature. Basing on the implemented researches, some climatologists draw a conclusion that people feeling is significantly better under the regime of round-the-clock ventilation notwithstanding some temperature rise inside the premises due to the input of the external air with highest temperature. The hygienic observations of conditions of people showed that the activity of the thermo-regulating organs became easier and better during ventilation.

Let's consider the possibility of provision of comfortable heat regime in the premises of the medical rehabilitation centers of the Sport Palace of in Baku. The following conditions were implemented as the criterion of comfortable heat regime in the premises:

1) *Average daily temperature of the internal air increases the average daily temperature of the external air not more than 1,5 °C;*
2) *Amplitude of temperature fluctuation of the internal air doesn't exceed 1,5°C.*

Domestic and operational heat emission is not taken into account when controlling the implementation of the mentioned conditions. This criterion was obtained from the investigations of V. N. Bogoslovsky [28] and other researchers. It should be noted that an assumption on the insignificant difference between the inside radiation temperature and the temperature of the outside air was used while obtaining the criterion. Later, this assumption will be substantiated.

The multiplicity of heat exchange was equal to 5 l/hour. It is necessary to state that the external enclosures met the requirements on summer and winter conditions of maintenance. As the target of calculation was to reveal the possibilities of comfortable heat regime provision in summer conditions by the construction means including the increase of the thickness of external heat isolation compared to the thickness required for winter conditions, during appointment of the initial version of premises we considered that the external enclosures meet the requirements only winter conditions for the implementation of researches. The premises was considered for two persons where the average daily amount of heat input is 160 W/hour. The mass of furniture relevant to 1 m^2 area of the floor was equal to 30 kg/m^2 [C_{ob}=0,6 W· hour/(kg · °C)].

While calculating the intensity of direct and diffuse solar radiation fallen on the external surface we accepted the parameters of the external air equal to t^{av}_H=26°C, A_{tH}=8°C, V_H=3.8m/sec for φ=40° according to the existing regulation.

Let's estimate the influence of orientation of the external barriers on the heat regime of the barrier the possible combinations given below:

Wall:

External facade with window and door of the balcony	S	N	N	S	E	W	E	W
External butt	E	E	W	W	N	N	S	S

The temperature of the inside air calculated on computer was taken as a criterion for determination of the most unfavorable orientation of the external walls (table 7.13).

Analysis of the calculation results presented in table 7.13 allows to conclude that:

a) *Orientation of the external facade of the wall with the window and door of the balcony to the west and the front wall to the South is the worst version.*

b) *The comfortable heat regime is not provided in the premises of the medical -recreation center where a part of the research was conducted.*

We calculated average daily and maximum value of the radiation temperature of the premises according to formula $t_R = \Sigma \varphi_{r-i} t_i$ (here φ_{r-i} is the coefficient of irradiation from people on different surfaces of the enclosure with temperature t_B in the position of people in the center of the premises). There are average daily values of the internal surface temperature of the enclosures in calculation of average daily value of the radiation temperature of the premises t_i, and there is maximum value of the internal surface temperature of the en closures in calculation of maximum value of the radiation temperature of the premises t_R.

The average daily and maximum values of the temperature on the internal surfaces of the enclosures and their beginning time obtained from the computer calculations, as well as the values of the irradiation coefficients are given in table 7.14.

According to the data given in table 7.14, the average daily value of the radiation temperature of the premises

t^{av}_R= 1,836 + 4,214 + 4,2 + 2,4 + 6,48 + 8,428 + 3,23 = 30,8.

Table 7.13 The values of the indoor air temperature*

Orientation of the façade and external front wall	t^w_a	A_{ta}	t^{max}_a	τ_{max}
S – E	29,7	3,2	32,9	17
N – E	29,4	3	32,4	17
N – W	29,4	2,9	32,3	18
S – W	29,7	3	32,7	18
E – N	29,7	2,8	32,5	17
W – N	29,7	3,6	33,3	18
E – S	29,8	3	32,8	17
E – S	29,8	3,8	33,6	18

Note: *τ_{max}- time of beginning of maximum value of the temperature of the internal air calculating from night, hour.*

** Shading of light opening of loggias was considered in calculation of the repetition of heat exchange is accepted as equal to 5 l/hour.*

Table 7.14. The values of the temperature of internal surfaces

Orientation of the façade and external front wall	t_i, °C	t^i_{max}, °C	$\tau_{max, r}$	φ_{r-i}
S – E	30,6	35,5	19	0,06
N – E	30,1	34,2	19	0,14
N – W	30	33,5	19	0,14
S – W	30	33,5	19	0,08
E – N	32,4	34,8	20	0,2
W – N	30,1	32,9	19	0,28
Light opening	32,3	39,9	16	0,1

For the calculation of maximum value of the radiation temperature of premises we will suppose that temperature variations in the internal surface of the inclosure will be described through the following dependence:

$$t_i = t_i^w + (t_i^{max} - t_i^w)\cos\omega(\tau - \tau_{max}) \quad (7.70)$$

Making calculations t_R for each moment of day, we will obtain that the radiation temperature reaches its maximum value at 18 h. (calculating from night): t^{max}_R = 2,1+4,8+4,7 + 2,7 + 6,9 + 9,2 + 3,8 = 34,2. Comparison of t^{cr}_R and t_R^{max} accordingly with $t^{av}_B$and t_B^{max} presented in table 7.13 (version W-S), shows that corresponding values of the temperature differ insignificantly.

In order to establish comfortable thermal regime in premises we carried out studies through increasing the thickness of the heat insulation material in coating for twice (I version), or increasing the solar protection of light opening by internal venetian blinds (II version), or both of them simultaneously (III version) and simultaneously increasing the multiplicity of heat exchange to 10 l/hour (IV version) (table 7.15).

We can come to the following conclusions on the basis of the results of calculations:

1. It is not possible to provide comfortable thermal regime in the premises of the medical-rehabilitation center by construction and operating means under climatic conditions of the Absheron peninsula and use of air conditioning devices is required. In addition, the thermal regime nearer to the comfortable can be provided in the premises of buildings through simultaneous implementation of the following conditions:

   a) Using the external venetian blinds;

   b) Increasing multiplicity of heat exchange to 10 l/hour.

   c) Increasing the thickness of the heat insulation material on the covering for twice in comparison with the value required for winter conditions.

2. The premises of the upper floor is located most unfavorably (in view of provision of comfort thermal regime) with the orientation of the facade wall with the light opening on the west and frontal wall on the south.

3. The radiation temperature of the premises and the temperature of the internal air differ insignificantly, when the difference decreases with approximation of internal conditions to comfort.

Table 7.15 The results of calculations of indoor temperature regime

№ of versions	Orientation of façade and external front walls	t_i^{av}	t^{max}_i	τ_{max}	t_a	t_R
I	S – E	30,2	35	19		
	N – E	29,8	33,9	18		
	N – W	29,6	33	19		
	S – W	29,6	33	19	29,4	29,8
	E – N	31,3	33,1	20	33,1	33,6
	W- N	29,7	32,5	19		
	Light opening	32	39,6	16		
II	S – E	30,1	34,4	19		
	N – E	29,6	33,3	19		
	N – W	29,5	32,4	20		
	S – W	29,5	32,4	20	29,4	30,1
	E – N	31,8	34,1	20	32,7	33,1
	W- N	29,5	31,9	19		
	Light opening	31,5	37,5	16		
III	S – E	29,7	34	19		
	N – E	29,3	32,9	19		
	N – W	29	31,9	20		
	S – W	29	31,9	32,2	29,9	29,2
	E – N	30,7	32,2	20	33,1	32,4
	W- N	29,1	31,4	19		
	Light opening	31,1	37,2	16		
IV	S – E	28,8	33,8	19		
	N – E	28,3	32,7	18		
	N – W	27,8	31,8	19		
	S – W	27,8	31,8	19	27,7	27,8
	E – N	29,6	31,6	20	32,1	32,1
	W- N	27,8	31	19		
	Light opening	30,2	37,3	16		

Note: *On the line-average daily value of the temperature of the internal air (traditional), under the line-maximum value.*

8. THERMOTECHNICAL CALCULATION OF OPEN PLANAR SPORT FACILITIES WITH REGULATED HEAT REGIME

8.1. General characteristics of open planar sport facilities and the requirements to their heat regime regulation system

Lawn areas for golf, rugby, football areas and so on are the most spread open sports facilities. Availability of lawn with steady trufgrass is the necessary condition for their functioning.

The main purpose of heating of the sports lawns is prolongation of the sport playing season. The period of grass growth is prolonged by heating and the green cover becomes capable of being undergone to heavy load. Heating of lawn may be implemented in sports areas where water passes through the ground and drainage system quickly, i.e. the field is practically unsaturated and has good gas exchange that conditions quick growth of rhizomes.

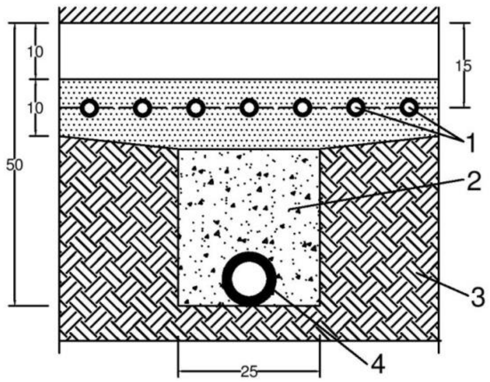
The heating system of open sport facility represents a row of heater elements located in the ground in some depth from the surface of the areas (picture 8.1). Heating power cables and pipes through which heat carrier is passed are used more frequently as heating elements: water, antifreeze or air (picture 8.2).

The temperature of beginning of the root system growth depends on the form of grass and fluctuates from 5 to 8 °C. Maximum growth of grass is provided under 16 – 18 °C temperature.

The duration of the work of heating system and as well as the time of its turning on in spring period is determined depending on the climatic region of location of the sports facility. In some regions, the heating season may begin from the first days of March. It is expedient to apply a layer of sand or peat on snow coating increasing the absorbing capacity of the solar radiation heat and later exerting useful influence on grass coating.

The field is heated by complete power for 24 hours a day nearly within 2,5 weeks at the beginning of heating season, later it is heated by 1/3 power for 24 hours a day nearly within 2,5 weeks and then by 1/3 power at nighttime for 10 hours a day. Heating is completely ceased when the average daily air temperature will be high enough for provision of natural growth of lawn. Periodical high day temperatures due to which heating in daytime is eliminated are taken into account during heating. The frozen layer of ground usually melts in a week and the coating of snow of 50 cm thickness usually melts in two weeks. The field may be prepared within 20 days at 120 W/m^2 heating power for beginning of playing season. The heating period begins at the end of October in autumn. At the beginning, the field is heated at night within 10 days with use of 1/3 power and then the heating period is increased up to round-the-clock heating with decreasing daytime temperature. 1/3 heating power is enough for autumn. At this time the growth of grass continues and the field may be suitable for use to the beginning of December. Heating is ceased at the end of November as well as the exploitation of the field.

Pic. 8.1 A scheme of construction of football field covering equipped with heating system



1.Heating elements; 2. Draining layer; 3. Underlying ground; 4. Drainage pipe.

The heating elements are put on the surface of the sports lawn in the cable trench the width of which insignificantly exceeds the width of the heating element when the heating system is constructed. The depth of putting of heating elements depends on the construction of planar sport facilities, character of competitions and the exploitation conditions. For example, this depth is 20 cm for football fields and 40-50 cm for facilities where the competitions on javelin, hammer or disc throwing are held. The distance or steps between the heating elements is determined by the requirement of uniformity of both the temperature fields and the grass coating and depends on the heat productivity of the heating system and fluctuates between 25-60 cm.

The cable trench is covered by sand during installation of the system and it improves the gas exchange of rhizomes and provides good condition for their nutrition and prevents clogging.

The heating cable has isolation and cover made of special rubber. The switch board of ready construction is installed for power input and it includes the main switch with the devices of limitation of thermal and short-term current overloading, automatic overload protection against current overload of different lines and single – phase amperemeter.

Connection of the switch board is implemented so that the heating chains may be connected either by triangle or star.

Wiring of the feeding cable from the switch board to the feeding points of the heating group is implemented by the cables through the cable channel with use of protecting pipelines on the laying under the athletic track. Both ends of the heating groups are driven to the switch board by cables through connection with sprockets or triangles.

Requirements on the heating system are determined by the maintenance conditions of sports facilities. Availability of good qualitative steady grass coating is such condition for lawn sport facilities, grass shall be evenly spread all over the field with fixed density, the grass lawn shall be quickly restored after holding competitions and trainings. Thereby, it is possible to form obli gatory conditions for the heating system.

1. Putting the roots of grasses in the depth 3 cm from the surface of the area with the temperature not lower than the fixed minimum. This minimum differs for different compositions of grass mixtures and is usually located within 8 to 12ºC [43]. Let's designate this minimum temperature as t_3, then $t_{h=3cm} \geq t_3$. On the basis of it, the necessary heat consumption is determined for heating of the sport area.
2. Establishment of uniform grass coating over the surface of the area. This requirement determines experimental values of parameters of the heating system-maximum possible step of heating elements while fixing their depth or minimum value of the ratio of depth of heating elements to their steps. It is necessary that the temperature of the field in the zone of growth of grass roots and the surface of the area to be uniform, i.e. the difference of the temperature of points located over the heating elements $t'_{o,э}$ and between two neighboring heating elements $t''_{o,э}$ don't exceed certain permissible value $\Delta t_{per.}$:

   $$t'_{o,Э}\big|_{\cdot h=h_Э} - t''_{o,Э}\big|_{\cdot h=h_Э} \leq \Delta t_{per}$$

   $$t'_{o,Э}\big|_{\cdot h=0} - t''_{o,Э}\big|_{\cdot h=0} \leq \Delta t_{per}$$

3. Establishment of a uniform temperature of the field surface and root - inhabited zone in the beginning and end of the heating element. In case of electro-heating, this requirement is implemented as the temperature of the heating cable is constant on full-length. This requirement is formed

in the following manner for hot water heating: the temperature difference at the beginning t_{beg} and the end t_{end} shall not exceed maximum allowable temperature:

$$t_{beg} - t_{end} \leq \Delta t_{max}$$

Beginning from the third requirement, the minimum allowable water or antifreeze consumption is determined.

The open sport areas with artificial heating have been constructed and commissioned in GFR, USA, Sweden, Canada and other countries. 10 football fields equipped with heating systems built in Sweden during 1964-1973 (table 8.1) [44].

The football fields in Sweden are heated in spring and autumn within 6-8 weeks and it allows to increase the period of their seasonal exploitation ave ragely for 4 weeks. Besides, heating provides the possibility of more intensive use of field due to quick restoration of grass coatings. Design of the heating system of the football fields in Sweden is very variable: for example, the step of heating elements changes from 0,1 to 0,7 m and laying of the depth of heating elements from 0,07 to 0,2 m.

In Great Britain, open sport facilities equipped with artificial heating mainly represent football fields and the field for playing Rugby. Heating cable is frequently used as the heating element of the system. The football field of "Everton football club" was equipped with the electric curing system in 1958 for the first time in the world. A year later, a field for playing rugby "Edinburg Murrifield" was commissioned with electro-heating. The first expe rience was unsuccessful. The heating system prevented the ice formation and thawed the falling snow in the field "Everton football club", but quick water diversion of the melt water from the surface was impossible because of insuf ficient drainage. As a result, the field soaked with water, became boggy and unfit for use. The heating system was dismantled after a year and half. But, the experience of construction of stadiums with artificial heating wasn't terminated in Great Britain. Designing and construction of these stadiums has been con tinuing since 1959 (table 8.2).

As in Great Britain, most of heated fields in USA are equipped with the electrical heating system (table 8.3). Electroheating cable in polyvinyl isolation is used as heating element. The use of heating in the football fields allows to increase their maintenance period for 1,5-2 months. The field is covered by synthetic (most of all, polyethylene) film at lower temperature of the external air of the field that allows to hold sport competitions on non-freezable ground at 20 degree below zero.

Table 8.1 Heating systems capacity of football fields in Sweden

Stadium	City	Years of construction	Heating method	Heating system capacity, W/m^2
Ullevi	Gothenburg	1964	Through electric cable	85
Ferendswallen	Reyashe	1965	Through hot water	60
Football stadium	Solna	1966	Through electric cable	60
Sederstadium	Stockholm	1966	Through hot water	250
Lingwallen	Linkoning	1968	Ditto	-
Hegslatten	Hernesand	1969	Through electric cable	50
Stadium	Stockholm	1970	Ditto	65
Tingwalla	Carlstad	1970		75
Baldarshon	Sundeval	1973		60
Stohswallen	Luleo	1973		70

Note: *1. Sederstadium is used in winter as artificial skating-rink. 2. Lingwallen stadium is heated with waste heat from thermal power plant. 3. All fields except the field of Lingwallen stadium is covered by synthetic film under lower temperature of the external air.*

Table 8.2 Stadiums with electroheating in Great Britain

Stadium	Years of construction	Field destination	Field area, m^2	Heating system capacity, W/m^2
Leeds, RFK Headinglay	1963	Rugby	8050	108
Scotch, Rugby Edinburg	1959		10050	108
Arsenal	1964	Football	7400	108

Table 8.3 Sport fields with electroheating in USA

Sports field	Years of construction	Depth of cable laying, m	Step of the cable, m	Heating system capacity, W/ m^2
Falkon, state Colorado, Colorado city	1966	0,15	0,3	50
Bush, Missouri state, Saint Louis city	166	0,15	0,3	90
Lambyou field, Wisconsin state Green day city	1967	0,15	0,3	100

As it is seen from the samples, in the majority of designed and commissioned sport facilities used the synthetic pipes through which heated antifreeze (or water) passes or heating cable as the heating elements. The cases of use of synthetic pipes with big diameter where the heated air is used as heat carrier are rather rare. The economic factors are considered first of all during selection of heating method (by hot water or power) including the cost of electrical energy in this region, the availability of heating main near the stadium and so on.

8.2. Mathematical model of heat transfer in the construction of open planar sport facilities and their realization method

Let's consider the feature of heat transfer process occurred in the soil of the sports ground. The soil represents capillary porous, polyphase body and, therefore, heat conduction is determined by different factors: heat conduction of solid skeleton of ground from one part to other at their contact places, molecular heat conduction in the environment filling intervals between particles, irradiation from one fraction to other one and convection of gas and moisture available in the pores of ground. It is necessary to state that the thermo-technical characteristics of soil changes over time and on the coordinates due to its heterogeneity.

Determination of the temperature field in the soil taking into account all factors of heat and mass transfer is very difficult. One of the ways of solution of this problem is the development of equivalent heat conduction models when the soil is considered as quasi -homogeneous body to which usual equation of heat conduction is applied. Then, the feature of heat and mass transfer is effective. The dependence of effective thermo-physical characteristics of soil on temperature can be neglected, as their variation in the interval from -50 to+50ºC where maximum fluctuation of temperature is practically observed in all geographical latitudes of the Caucasus and it is quite insignificant.

It is also possible to solve the equation on heat conduction without taking into account mass conduction. It is explained by the fact that the processes occurred in soil are characterized by small temperature difference and proceed slowly over time. The specific weight factor conditioned by heat transmission through moisture doesn't exceed 10% [42]. Besides, the effect from transfer of moisture conditioned by temperature gradient is partially compensated by counter motion of moisture under the influence of gravity force. The influence of mass transfer on the temperature regime of soil through changes of effective thermo-technical characteristics of soil depending on moisture is considered during calculation.

Effective thermo-thechnical characteristics are obtained in the form of empiric formula and tables of A.F.Chudnovsky and his students practically for any ground of the Caucasus [42].

According to early studies [39,45], we will consider that the maintenance period of open sport facilities with lawn may be conditionally divided into four periods:

1. Period of thawing of frozen soil, thawing of snow and establishment of temperature conditions for the grass coating growth. The duration of this period is 2 – 2,5 weeks. Non -stationary temperature – moisture regime of soil is characteristic for it. Thawing of soil near the heat source begins after activation of the heating system. Let's divide the soil into four layers upon the depth. The first layer includes snow (δ_1) and part of frozen soil from the surface to the upper boundary of the thawing zone (δ_2) located above and below the heat sources plane; the second layer includes the thawing zone of ground (δ_3); the third layer (δ_4) consists of frozen soil from the lower boundary of the thawing zone till H depth, m (frost penetration depth) and the fourth layer comprises a zone from non-frozen soil from depth H, m to depth H where constant temperature is set. Let's designate the temperature, thermo-technical characteristics of the soil layers by indexes corresponding to the numbers of layers. It is necessary to take into account that the composition of each layer may include the parts of soil with different thermo-technical characteristics.
2. Period of grass coating growth. The surface of the area and root inhabited zone of soil is supported under stationary temperature regime providing normal growth of grass. It is expedient to cover the surface of the soil with synthetic film in order to form interlayer with thermal resistance R between it and the area in order to decrease the energy consumption for soil heating. The duration period is 2 – 4 weeks.
3. The period of holding competitions and trainings. During this period the temperature regime is formed providing storage and restoration of grass coating of the area. At this time, it is expedient to cover the surface of the area with synthetic film when no training or competition is held.

It is possible to write the equation of heat balance of the surface of the construction of open planar sport constructions in the following form:

$$Q_c + Q_r + Q_{sol} + Q_T = 0 \tag{8.1}$$

where Q_c -the convective heat flow between the surface of the construction and the air washing it; Q_r-radiant heat flow between the surface of the const ruction and environment; Q_{sol}-heat flow conditioned by solar radiation and Q_T -heat flow entered onto the surface from ground massive.

The value of the convective heat flow Q_c (W) may be calculated according to Newton formula:

$$\mathrm{Q_c = a_c(t_a - t_e)F_a} \tag{8.2}$$

where α_k - the coefficient of convective heat exchange, W/(m^2 · ºC); t_a, t_e – corresponding temperature of the surface of the areas and external air, ºC; F_a – square of the surface of area washed by air, m^2.

Availability of grass coating, thawing of snow, character of air flow (laminar or turbulent) on the surface of the air exerts defined influence on the value of the coefficient of the convective heat exchange α_c. The value of α_c is calculated according to the following formula during the engineering calculations:

$$a_e = \eta 10\sqrt{V} \tag{8.3}$$

where V -the wind speed on the earth level, m/c; η – coefficient accepted to be equal to 0, 3 when the grass coating is available and to 1 when it is not available.

The radiant heat flow between the surface of the area and the environment may be calculated by the following formula:

$$_r = \eta \sum_j C_0 \in_{a-j} [\left(-\frac{t_a+273}{100}\right)^4 - \left(\frac{t_j+273}{100}\right)^4]\varphi_{a-j}F_a \tag{8.4}$$

where C_0, $\varepsilon_{a\text{-}j}$ -coefficient of radiation of absolute black body equal to 5,77 W/(m^2 · ºC) and the given coefficient of radiation in heat exchange between grey bodies, respectively; $\varphi_{a\text{-}j}$-coefficient of radiation to the environment by the surface of area; t_j – temperature of the surrounding surface, ºC.

In this case, firmament and the buildings located near the construction can be considered as surrounding areas. Neglecting the influence of the buildings located nearby we accept the following in the engineering calculations:

$$\varphi_{a-sky} = 1;\ \in_{a-sky} = \in_a \in_{sky} \tag{8.5}$$

$$Q_r = \eta C_0 \in_a \in_{sky} b_{a-sky}(t_a - t_{sky})F_a = a_r(t_a - t_{sky})F_a$$

where $b_{a\text{-}sky}$-the correcting coefficient (index "sky" concerns the feature of the surface of the sky); α_r – coefficient of radiant heat exchange, W/(m^2 · ºC).

The heat flow consumed for thawing of snow is calculated by the following formula:

$$Q_{sn} = r\rho \frac{\partial y}{\partial T} F_a \tag{8.6}$$

where *r*-the specific heat of snow melting, W·hour/kg; ρ-the density of snow kg/m^3; *y* – thickness of the snow coating, m; T- time, hour.

The heat flow conditioned by solar radiation is calculated by the following formula:

$$Q_{sol} = \rho I F_a \quad (8.7)$$

where ρ – coefficient of solar radiation absorption by the surface of area; *I* – the value of the total solar radiation, W/m^2.

The following formula is used for the calculation of the heat flow entered onto the surface from the soil massive:

$$Q_H = -\lambda \frac{\partial t}{\partial y} F_a \quad (8.8)$$

where λ – the equivalent coefficient of heat conduction, W/(m^2 · ºC).

It is necessary to remember that the values of both the wind speed and the solar radiation intensity may change repeatedly in a short time interval. It is appropriate to use their average values during calculations. Average hourly values are used for solar radiation and average daily values are used for wind speed. The heat flow calculated according to formula (8.8) also is relevant to the case when the area is covered by film.

The equation of heat conduction for the material (soil) where phase transitions occur may be expressed in the following forms:

$$\frac{\partial H}{\partial T} = \frac{\partial}{\partial x}\left[\lambda \frac{\partial t}{\partial x}\right] + \frac{\partial}{\partial y}\left[\lambda \frac{\partial t}{\partial y}\right] + Q_{source}(x, y, T) \quad (8.9)$$

$$H = \int_0^t [c(y)\gamma(y) + \delta\,(\xi - t^*) L\omega\rho_W r] d\xi \quad (8.10)$$

where δ (ξ-t*)-the delta function of Dirac, 1/ºC; t*-the temperature of phase transition, ºC; *r*-specific heat of the phase transition, (W·hour)/kg, ω-humidity of soil, unit quota; L-ice content of soil, unit quota; ρ_B-density of water, kg/m^3; Q_{source} -massive of the heat sources of in soil providing the regulated heat regime, W/m^3

$$c(y)\gamma(y) = \begin{Bmatrix} c_1(y)\gamma_1(y) \text{ at } t \geq t^* \\ c_2(y)\gamma_2(y) \text{ at } t \geq t^* \end{Bmatrix} \quad (8.11)$$

The size ∂H/∂t│t = t* turns to endlessness and the function H(t) has the rupture of the first kind with galloping:

$$H(t^* + 0) - H(t^* - 0) = r\omega L\rho_W \quad (8.12)$$

We will consider that the temperature in certain depth from the surface of the area is constant and equal to t_r, and heat flows on the surface of the area x=l_1 and x=l_2 are equal to zero, i.e. heating of soil doesn't occur at the distances l_1 and l_2 from the center of the area.

The power of heat source in the soil providing regulated heat regime can be fixed by the following formula (*under the condition that the source is dotted*).

$$Q_{source} = q\delta(x - x_0)\delta(y - y_0) \quad (8.13)$$

where q-the density of heat flow, W/m; x_0 and y_0 – coordinates of the center of the heat source.

It is expedient to use finite- difference method including: locally one method allowing to substitute the initial two-dimensional equation with two singles, integro-interpolation method with implicit scheme for solving single equations, substituting (smoothing) of δ function for solving the problem [20, 46].

As a result of the researches [45] carried out to study the impact of the constructive and heat engineering indicators of the open plane sport facilities on its thermal regime it was determined that the heating system with 120 – 135 W/m^2 power is enough for the establishment and maintenance of normal temperature regime of sports areas under climatic conditions of average latitude of Russia at the temperature of the external air up to – 10 ºC.

The surface area shall be covered by synthetic film at the temperature of the external area lower than -5ºC in order to prevent frost penetration into the turf coating. The film shall not be removed for a period more than 4 hours. In case of disconnection of the heating system for any reason, the area shall always be covered by synthetic film. The rational depth for laying the heater elements is 0,3-0,4meter. One of most effective methods of coverage of the surface of area is the use of synthetic film having no heat capacity. As a rule, the thermal resistance of the air space partially occupied by grass is 0,16–0,2m^2·ºC/W, where the energy cost of heating of a sport area decrease averagely to 50%. Installation of one more dry air streak located at some distance from the first one by covering the area with film increases general thermal resistance of the air space up to 0,4 m^2·ºC/W. The cost of heating is reduced averagely to 120-130%.

The data on the change of soil humidity during the heating system operation are shown in tables 8.1-8.3. The mass moisture of the soil layer higher the plane of the heating elements decreases averagely to 7-8%, and redistribution of humidity occurs. The highest humidity is observed in the root inhabited layer of soil with 3 cm thickness located on the surface of the area.

It was determined that the value of the effective coefficient of the soil heat conduction λ_s taking into account the mass transition factors for heat engineering calculations of sport area construction with heating should be accepted as following: λ_s=1W/(m^2·ºC) during calculation of cooling of the soil of sport area when the heating system is switched off; λ_s=1,3 W/(m^2·ºC) under open surface of the area when the heating system is switched on; λ_s=1,5W/(m$^2\cdot$°C) under covered surface of the area when the heating system is switched on.

The annual cost of heating of the football fields has also been determined for different cities of CIS countries (see table 8.4).

The method developed by D.Y. Khromets [45] for engineering calculation of the energy cost of sport facilities heating is based on the following information.

Baseline information:

a) *Heating type (by electrical or hot water);*
b) *The depth of laying of heating elements-h, determined from the exploitation conditions of sport facilities;*
c) *Step of heater elements-s accepted for the initial calculation to be equal to s= h-1,5h, afterwards determined from the conditions of uniformity of the temperature field of the surface of the area and the root inhabited zone (for lawn areas) and from the conditions of minimum expenditures;*
d) *Diameter of the heating elements – d;*
e) *The depth h_3 from the surface of the area on which the predetermined temperature t_3 shall be provided;*
f) *Temperature t_3 required for maintaining of normal conditions of sport facilities;.*
g) *Maximum permissible difference of temperature in the points of the surfaces of the area located one from other at a distance of 0,5 s – $\Delta t_{per.}$;*
h) *Maximum permissible difference of temperature of the surfaces of the area-Δt_{max} in the beginning and the end of the heating element(for hot water heating);*
i) *City where the sports ground is designed or constructed;*
j) *Date and month of the beginning and the end of the seasonal exploitation of the area;*
k) *Materials of the layers of the sports ground foundation (for lawn areas-types of soil).*

Table 8.4 Annual cost of the heat (Gcal/m^2) for heating of the football fields

Cities	Electrical heating		Heating by hot water	
	From March to November	Year- round	From March to November	Year- round
Arkhangelsk	0,279	0,633	0,294	0,661
Baku	0,032	0,06	0,032	0,06
Volgograd	0,112	0,403	0,121	0,424
Kemerovo	0,311	0,767	0,326	0,793
Leningrad	0,175	0,446	0,187	0,471
Moscow	0,165	0,461	0,177	0,485

Novosibirsk	0,309	0,776	0,321	0,802
Kiev	0,11	0,332	0,12	0,353
Kerch	0,072	0,184	0,088	0,202
Simferopol	0,089	0,19	0,099	0,208
Minsk	0,141	0,395	0,156	0,418

Calculation of the energy cost of the heating of sports ground is implemented as following:

1. The temperature of the coldest days over the period of the seasonal exploitation of sport grounds is taken as the calculation temperature of the outside air $-t_O$.
2. The coefficients of heat conduction -λ of the layers of the sports grounds foundation are determined according to the existing regulation [20]. The coefficient of heat conduction of soil is determined using the empiric formula developed for lawn sports grounds:

$$\lambda = \rho(c + 0{,}01\omega)[m_1(\omega - m_4)^2 + m_2\rho + m_3]10^{-3}$$

where λ-the coefficient of heat conduction of the soil layers; ρ – soil density; c – specific heat capacity of the soil; ω – gravimetric moisture of soil; m_i – coefficients depending on the soil type when i = 1, 2, 3, 4 (table 8.5).

Table 8.5 Empiric coefficient for different soil types

Type of soil	m_1	m_2	m_3	m_4
Ordinary black earth	-0,013	3,1	1,21	20
Dark- brown soils	-0,017	2,2	1,9	18
Gray earth	-0,0062	2,7	-0,2	18
Southern black	-0,0104	2,4	0,68	20
Sod clay soil	-0,02	3,1	1,4	20

The following data can be used for previous calculations when necessary information is absent:

a) λ=1,4 W/(m^2·°C)-in calculation of cooling down of sport facilities when the heating system is switched off;
b) λ=1,7 W/(m^2·°C) -under open surface of the facilities when the heating system is switched on;
c) λ=2 Watt/(m^2·°C)-under covered surface of the facilities when the heating system is switched on.

The value of thermal resistance of the air space partially occupied by grass $-R_{a.s.}$ is equal to 0,14 (m^2 · °C)/W.

3. α coefficient is calculated:

$$a = \frac{h_3/\lambda}{\frac{h_3}{\lambda} + 0{,}043 + R_{a.s.}}$$

4. The conditional thermal resistances R_1 (for hot water heating) and R_2 are calculated:

$$R_1 = \frac{1}{2\pi\lambda} ln\left[\frac{2s}{\pi d} - sh\left(2\pi\frac{h}{s}\right)\right];$$

$$R_2 = \frac{1}{2\pi\lambda} ln[ch\pi(h + h_3)/s]/[ch\pi(h + h_3)/s];$$

5. Water (antifreeze) consumption is calculated during use of hot water heating necessary for establishment of uniform temperature field of the surface.

$$\omega = \frac{l}{c}[\frac{a(t_\ni - t_H)}{\Delta t_{max} R_2} + \frac{1}{R_1}]$$

where ω -water consumption (antifreeze), kg/hour; l -length of the heating element, m; c – heat capacity of water (antifreeze), W·hour/(kg · ºC).

6. Dimensionless value of H is calculated during use of hot water heating:

$$H = 2cWR_1/l$$

7. The heat consumption for maintaining of the predetermined temperature of sports ground is determined for both hot water heating Q_w and electrical heating Q_{el}.

$$Q_w = a(t_\ni - t_H)/R_2(H + 1)/(H - 1)$$

$$Q_{el} = a(t_\ni - t_H)/R_2$$

8. The temperature of the heating element is determined for electric heating –$t_{el.}$ and the temperature of water (antifreeze) is determined for hot water heating – $t_{w.}$:

$$t_{el} = a(t_\ni - t_H)\left[\frac{R_1(H + 1)}{R_2(H - 1)} - 1\right] + t_3$$

$$t_w = a(t_\ni - t_H)\left[\frac{R_1(H + 1)}{R_2(H - 1)} + \frac{\pi\lambda_w + d_H(d_H + d_a)}{2\delta_{w^s}} - 1\right] + t_3$$

9. The annual heat consumption for maintaining of the predetermined temperature of sports ground is determined for hot water heating $Q_{w.an.}$ and electrical heating $Q_{el.an.}$

$$Q_{w.an.} = \frac{Ha}{sR_2(H - 1)}\sum_{i=1}^{n}(t_{pi} - t_{oi})z_i$$

$$Q_{el.an.} = \frac{a}{sR_2}\sum_{i=1}^{n}(t_{pi} - t_{oi})z_i$$

where t_{oi}, t_{pi}-the temperature of the outside air and the predetermined temperature of soil, ºC; z_i -duration of i period of the heating system operation, hour; n – number of separate periods of the heating system operation.

During calculating the duration of the heating system operation period, it was admitted that every month has 30 days.

10. Economically optimum distance between the heater elements for water heating $S_{opt..w}$ and electrical heating $S_{opt.el}$ is determined:

$$S_{opt.w.} = \frac{C_k}{CqT} \frac{H-1}{Q_{w.an.}[M+(N-1)(H-1)}$$

$$S_{opt.el.} = \frac{C_k}{CqT} \frac{1}{Q_{el.an.}(N-1)};\ M = \frac{\frac{2\pi h}{s} cth \frac{2\pi h}{s} - 1}{ln[\frac{2s}{\pi d} sh(2\pi \frac{h}{s})};$$

$$N = \frac{\frac{\pi h_+}{s} th \frac{\pi h_+}{s} - \frac{\pi h_-}{s} th \frac{\pi h_-}{s}}{lnch \frac{\pi h_+}{s} - lnch \frac{\pi h_-}{s}}$$

where C_q-the cost of the units of heat energy, man./(Watt·hour); T-normative for holding uniform consumptions, l/year accepted 0,08;C_k-value of 1m heating element per a day, man.; $h_+ = h + h_3$; $h = h - h_3$

The value of the heating elements step is included in the formula for determination of M, N, H, $Q_{el..an.}$ and $Q_{w.an.}$ Therefore, for the case when the values of $S_{opt.w}$ or $S_{opt.el.}$ significantly differs from previously accepted S, the calculation is repeated with new step of the heating elements S= $S_{opt.w}$ or S=$S_{opt.el}$.

9. SKATING RINKS WITH ARTIFICIAL ICE

9.1. Mathematical model of heat transfer in the skating rink with artificial ice

The skating rinks with artificial ice are built on special foundation equipped with devices for its cooling till the temperature below 0 ºC (picture 9.1). Cooled foundation is overwatered and afterwards, freezing forms icy area. Rinks with artificial ice are built in closed premises or rarely outdoors. Unfavorable atmosphere conditions and solar radiation significantly influence both the technological conditions of the rinks maintenance and energy consumption for its cooling. Year-round maintenance of rinks with artificial ice under reliable provision of ice quality is possible in the closed premises. But, the energy consumed for the rink cooling significantly increases in summer, as the tem perature of the premises is high. Therefore, air conditioning system is needed. It leads to the increase of the capital expenditures of the construction of cooling devices and their maintenance cost. Besides, the premises where the rink with artificial ice is built must meet a number of specific requirements. Particularly, it should have minimum possible area of light openings equipped with effective solar protection eliminating direct fall of solar beams on the ice surface. Lighting devices should emit less convective heat to the air of the premises and radiant heat to the ice surface. Location of lamps should be so that the radiant energy produced during their work fall uniformly on the surface of ice.

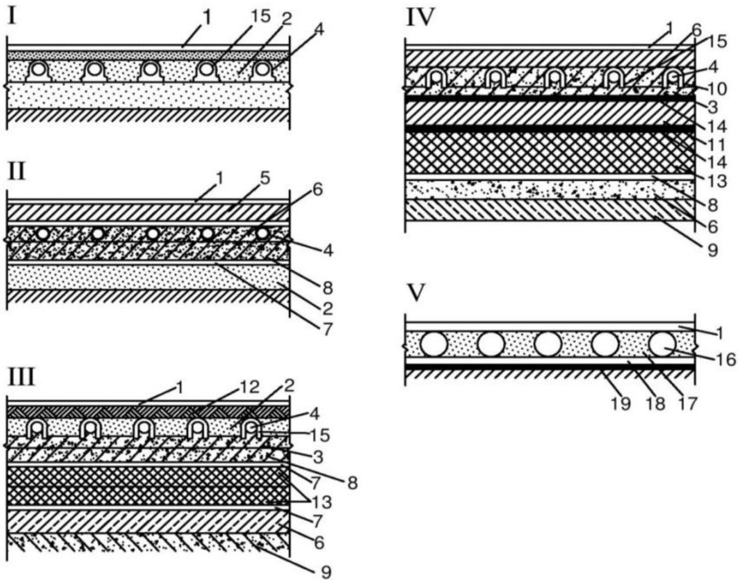
Cooling of the foundation of the rink with artificial ice is implemented by cooling agents circulated through the pipes laid on the bottom plate. A layer of effective heat insulation which should be reliably protected against penet ration of moisture from above and below is laid on the bottom plate in order to decrease the energy consumption. The heat isolation layer has small heat accumulation capacity, it is cooled and heated quickly and thereby, the energy consumption decreases during freezing of ice.

Special attention during construction of the rink with artificial ice is paid to the temperature tensions, the danger of which significantly increases when moisture penetrate to the foundation plate. The case is that the volume of water increases when it is frozen that leads to the formation of frost heaves destroying the foundation plate.

Taking into account high capital expenditures of construction of target rink with artificial ice further transformable rinks with artificial ice have been developed [47].

The requirement on the cooling system of the rink is determined by the conditions of maintenance of the ice coating and depends on sport types for which the ice-rink is intended. The quality of artificial ice-rink is estimated mainly by uniformity of temperature of its surface. This parameter depends on a number of factors including: step and diameter of cooling pipes; the cost of cooling agent and the difference of its temperature in the entrance and exit from the pipe construction of field; the thickness of concrete layer above pipes and heat exchange conditions of the ice surface. The values of these factors are determined based on the heat engineering calculation of construction of the rink with artificial ice. Proper selection of heat isolation of the cooling plate which protects the underlying layers of soil against freezing as well as against possibility of swelling and destruction of the foundation of the rink has special importance during designing.

Pic. 9.1 Schemes (I, II, III, IV and V) of construction of rinks with artificial ice



1. ice; 2. sand; 3. concrete mat; 4. pipes; 5. cement covering; 6. concrete; 7. two layers of tar on mastic; 8. porous concrete; 9. concrete foundation; 10. reinforced concrete; 11. cement covering on grid; 12. graphite coating; 13. cork plates 2 x 50 mm on mastic or other heat insulation; 14. asphalt; 15. fastening of pipes to mats; 16. pipelines of freezing installations of 19 mm diameter; 17.turf; 18. foil made of synthetic material; 19. coating of the stadium or athletic track.

The use of effective heaters is associated with reducing of energy consumption for the plate cooling: the heat isolation decreases heat leakage from the soil to the cooling plate, protects the surface of the plates in the transformable rinks against the condensation of moisture from air on it during performances not related to ice. The use of heating system for preventing soil freezing under the rink is applied very rarely. The training rink "Crystal" in Lujniki (Moscow city) supplied with low voltage electric heating system can be cited as an example.

The choice of any design for the artificial rink foundation should be based on the knowledge about the temperature field of the rink foundation at different stages of exploitation as well as on the knowledge of the temperature field of soil under the rink foundation.

The mathematical model of heat output in the artificial ice-rink design contains the following main equations: equation of heat balance of the ice-rink surface, equation of heat transfer in multilayer design of the rink, equation of heat exchange of the cooling agent – rink structure and equation of heat transfer of the rink foundation.

Generally, the equation of heat balance of the ice-rink surface has the following form:

$$Q_C + Q_{r.l} + Q_{r.s} + Q_r + Q_{ph} + Q_H = 0 \qquad (9.1)$$

where Q_c -the convective heat flow between the ice-rink surface and the air washing it, W; $Q_{r.l}$-radiant heat flow on the account of long wavelength radiation, W; $Q_{r.s}$- radiant heat flow on the account of short wavelength radiation, W; Q_r-heat flow conditioned by absorption of solar radiation (for rinks constructed in the open air), W; Q_{ph} – heat flow of heat (cold) on the surface of ice-rink conditioned by phase transition, W/m^2; Q_t-heat flow from the surface to the construction inside, W.

The convective heat flow between the ice-rink surface and the air washing it is calculated according to the Newton law.

$$\mathrm{Q_c = a_c(t_a - t_s)F_s} \qquad (9.2)$$

where α_c – the coefficient of convective heat exchange, W/(m^2 · °C); t_a and t_s–temperatures of air and surface, °C; F_s – area of the rink surface, m^2.

The coefficient of convective heat exchange between the inside air and ice surface may be determined from criterion equations depending on the character of convection (forced or free). Processing of criterion equations for considered conditions of heat exchange between the ice surface and air leads to the following formula for calculation of the coefficient of convective heat exchange [9]:

Under forced convection:

$$a_c = 5{,}6V^{0,8} \quad (9.3)$$

where V – the speed of air motion near the ice surface, m/sec.

Under free convection:

$$a_c = 1{,}16\sqrt[3]{(t_a - t_s) + 60V_0^2/l} \quad (9.4)$$

where V -the speed of air motion on the ice surface, m/sec, l -characteristic size of the surface, m.

The radiant heat flow on the account of long wavelength radiation may be calculated according to the following formula:

$$Q_{r.l} = a_r(t_{\,i.s.} - t_{s.s.})F_s \quad (9.5)$$

where α_r-the coefficient of radiant heat exchange between the ice surface and surrounding surfaces, W/(m^2 · °C).

The value of the coefficient of radiant heat exchange may be accepted as 4,5 F_s/F_f, where F_f – the area of the floor surface (m^2), for the considered conditions of the heat exchange of the rink surface located in the premises.

During calculation of the radiant heat flow caused by short wavelength radiation, we will consider that it enters from the lighting source and the intensity of this flow may be calculated according to the following formula:

$$Q_{r.s} = I_{s.w}F_s/F_{pre} \quad (9.6)$$

where $I_{s.w}$ – the intensity of flow of short wavelength radiation emitted from the lamp, W; $F_{\,pre}$ – area of the internal surface of the premises, m^2.

The intensity of the total solar radiation I,W/m^2 and coefficient of absorption of ice by its surface ρ is determined according to the reference data for the rinks constructed in the open air, thus:

$$Q_{rad} = \rho I F_s \quad (9.7)$$

The indoor air always contains some amount of moisture in a form of water vapor that conditions its humidity. The main source of moisture input in the gyms excluding gyms with pools is the people present in it. An adult person in calm condition discharges 12,5 g/hour moisture when breathing and 33 g/hour moisture from the surface of skin. During intensive movement the total amount of moisture discharged by a person is 100-300 g/hour. Air may assimilate excessive moisture, which the premises eliminates during ventilation. The amount of humidity in the air is determined by its moisture content d (g/kg), of dry part of humid air. Besides, its humid condition is characterized by elasticity or partial pressure of water vapors e (Pa) or relative humidity φ (%).Air has certain moisture retaining capacity. For example, at 20°C temperature every 1 kg dry air contains nearly 15g water vapors and at 12 °C temperature nearly 1.5 g.

The amount of moisture condensed on the surface of ice-rink i (kg/hour) may be determined according to the following formula:

$$i = 0{,}001\beta(e_a - e_s)F_s$$

where β-the coefficient of heat exchange of the surface, g/(m^2 ·hour · MPa); e_a and e_s-elasticity of water vapors in the air of the premises and on the ice surface, MPa.

The value of β depends on temperature, moisture and air motion in the premises and also the temperature of the surface. The value of β may be calculated by the following formula under the conditions of natural convection [27]:

$$\beta = 42{,}9(t_R - t_s)^{\frac{1}{3}}(e_a - e_s)^{2/5}$$

The amount of heat produced during condensation of moisture on the ice surface is determined by the following formula:

$$Q_f = r_s i$$

where r_s-the specific heat of moisture evaporation (condensation), W· hour/kg.

The water layer on the surface of the foundation plate freezes bottom up forming a layer of ice with variable thickness *y*. Its lower movable boundary always has freezing temperature. Transition from one aggregate condition to other one happens in this boundary. This process requires transition heat -the specific heat of freezing of water *r*, W·hour/kg. Then the equation of heat balance on the boundary of water – ice has the following form:

$$\lambda_1 \frac{\partial t_1}{\partial y} - \lambda_2 \frac{\partial t_2}{\partial y} = r\rho \frac{\partial y}{\partial T} \quad (9.8)$$

where λ_1 and λ_2 -heat conduction of water and ice, W/(m^2 · °C) and t_1 and t_2 -the temperatures of water and ice, °C, respectively; ρ-density of water, kg/m^3.

It should be noted that at the beginning of freezing t_2 and λ_2 are the temperature and coefficient of heat conduction of the material of the foundation plate. The temperature of the upper layer of water is higher than of the lower layer during freezing out, therefore, convectional movement is absent in the water layer and its temperature field is described by usual equation of heat conduction as in the ice layer.

The temperature field in multilayer construction of the rink located under the ice layer may be described by three-dimensional equation of Fourier. In this case, the following assumptions are expedient for simplification of the task:

1) *Thermal and physical characteristics of the materials of rink layers are not dependent on the temperature and remain constant within the layer;*
2) *The rink area has great dimensions, so the influence of the adjacent part of floor on its temperature field can be neglected.*
3) *Cooling pipes are a lot enough so that their number could be considered as endless. The calculation model represents a massive restricted by two vertical planes the distance between which is equal to the step of heating elements.*
4) *The rink construction is restricted by a plane at the bottom to which the temperature or heat flow is given from the soil massive.*

The researches show that the volume of the heat flow from soil to the rink foundation doesn't exceed 7W/m^2 and contains 5-10% of the total amount of heat flow to the rink in case of isolated rink [47].

The cooling agent movement in the pipe may be considered as fixed axial-symmetric movement of viscous incompressible fluid, the flow energy equation of which is in the following form:

$$c\rho V_x \frac{\partial t}{\partial x} + c\rho V_r \frac{\partial t}{\partial r} - \left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\lambda\frac{\partial t}{\partial r}\right) + \frac{\partial}{\partial x}\left(\lambda\frac{\partial t}{\partial x}\right)\right] = 0 \qquad (9.9)$$

where c, ρ and λ – specific heat capacity, W· hour/(kg · °C), density, kg/m^3, coefficient of heat conduction of the cooling agent, W/(m^2·°C), respectively; V_x and V_r-components of flow speed of the cooling agent on the coordinate axis, m/sec.

As the transfer of heat by heat conduction in the direction of flow movement of the cooling agent is lower in comparison with the convective heat transfer in it, then $c\rho V_x \frac{\partial t}{\partial x} >> c\rho V_r \frac{\partial t}{\partial r}(\lambda \frac{\partial t}{\partial x})$. Considering that the coefficient of heat conduction of the cooling agent is constant and the velocity the flow profile doesn't change on the pipe section, i.e. V_r=0 V_X=V=const, we integrate the equation of energy and obtain:

$$c\rho V \int_0^R r\frac{\partial t}{\partial x}dr - \lambda\int_0^R \frac{\partial t}{\partial r}dr - \lambda\int_0^R r\frac{\partial^2 t}{\partial r^2}dr = 0 \qquad (9.10)$$

We calculate the third integral in formula (9.10) by parts:

$$\int_0^R r\frac{\partial^2 t}{\partial r^2}dr = r\frac{\partial t}{\partial r}\Big|_{r=0}^{r=R} - \int_0^R \frac{\partial t}{\partial r}dr \qquad (9.11)$$

Let us determine the average temperature cooling agent on the pipe section as following:

$$t^* = \frac{1}{\pi R^2}\int_0^R rtdr \quad (9.12)$$

and taking into account that

$$\lambda \frac{\partial t}{\partial r}\Big|_{r=0}^{r=R} = a_c(t - t^*) \quad (9.13)$$

we receive

$$\frac{dt^*}{dx} = \frac{2a_c}{\pi c\rho RV}(t - t^*) \quad (9.14)$$

The coefficient of convective heat exchange α_c for canals of different sections under turbulent regime of fluid flow movement in them, i.e. at R>2500 is determined from the following equation:

$$Nu = 0{,}018Re^{0{,}8} \quad (9.15)$$

where Nu = $\alpha_c d_{eq}/\lambda$ – Nusselt number, Re = V d_{eq}/v – Reynolds number, $d_{eq.}$ – characteric size, m; v – kinematic viscosity of the fluid, m2/sec.

The average temperature of the cooling agent is taken for calculation of the heat engineering coefficient of the cooling agent, and d_{eq} – equivalent diameter (table 9.1) for determining size, equal quadruple area of the cross section of the channel divided into complete wetted perimeter not depending on which part of this perimeter participates in heat exchange.

As a rule, the cooling agent (solution of calcium chloride, ammonia and etc.) is practically non-transparent for the flow of long wavelength radiation and therefore, the radiant heat exchange between the walls of the channel can be neglected.

Taking into account that the temperature of the pipe walls t_{pw} don't change across the length, and the temperature in the entrance of the pipe is equal to t^*_0, we obtain the following by solving equation (9.14):

$$t^* = \left(t_0^* - t_{pw}\right)e^{-\frac{2stx}{\pi R}} + t_{pw} \quad (9.16)$$

where st = $\alpha_c/c\rho v$ – Stansune criterion, the measure of ratio of heat transfer intensity to specific heat content of the cooling agent flow in the pipe.

It should be noted that the consumption of the cooling agent in the pipe at its constant temperature is not the simple characteristic of the amount of the heat removed by it without indicating the area of cross section of the pipe for which this consumption is calculated.

Table 9.1 Values of characteristic sizes of the channels with different forms of section

Cross sectional shape	a/b	d_{eq}
Rectangular	~0	2a
	0,1	1,82a
	0,2	1,67a
	0,25	1,6a
	0,333	1,5a
	0,5	1,33a
Square with sides a	1	a
Circle of 16 mm radius	-	2

The simple characteristic of the amount of the removed heat is the value stated in the index of exponents.

Let's rewrite equation (9.16) in the following form:

$$\frac{t^*-t_{tw}}{t_0^*-t_{tw}} = e^{-2stx/\pi R} \qquad (9.17)$$

It is easy to determine from the last equation the conditions under which the temperature of the cooling agent in the pipe practically doesn't change along its length.

As a result, we obtain the following system of equations describing heat transfer in the construction of the rink with artificial ice:

$$c(y)\rho(y)\frac{\partial t}{\partial T} = \frac{\partial}{\partial x}\left(\lambda\frac{\partial t}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda\frac{\partial t}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda\frac{\partial t}{\partial z}\right) + 2\pi R a_c[t(x, y_0, z_0) - t^*]\delta(y - y_0, z - z_0); \qquad (9.18)$$

$$\frac{\partial t^*}{\partial x} = \frac{2a_c}{\pi c\rho RV}[t(x, y_0, z_0) - t^*]. \qquad (9.19)$$

$$y = 0 \ -\lambda\frac{\partial t}{\partial y} = a_c(t_a - t) + a_l(t_{sur} - t) + I_c\frac{1}{F_{pre}} + \rho I + \frac{r_s i}{F_s} \ ; \qquad (9.20)$$

$$y = y(T)\lambda_1\frac{\partial t_1}{\partial y} - \lambda_2\frac{\partial t_2}{\partial y} = r\rho\frac{\partial y}{\partial T}; \qquad (9.21)$$

$$y = h_i - \lambda_i\frac{\partial t_i}{\partial y} = -\lambda_{i+1}\frac{\partial t_i}{\partial y}, t_i = t_{i+1} \text{ at } i = 23, \dots\dots, n \qquad (9.22)$$

$$y = h_{n+1} - \lambda_{n+1}\frac{\partial t_{n+1}}{\partial y} = q_b \text{ or } t_{n+1} = t_b. \qquad (9.23)$$

The boundary conditions for planes and the perpendicular ice plane is the equality of heat flows to zero. The initial conditions τ=0, t (x, y, z)=const; x = 0, t = t*.

It is designated in the system of equations that: δ ($y-y_0$, $z-z_0$)-Dirac function, l/m; y_0, z_0 -coordinates of points with the initial regime parameters, m; t (x_0, y_0, z_0)-temperature in points with the initial regime parameters, °C; q_b , t_b– heat flow, W/m^2 or temperature °C of soil in the depth h_{n+1} from the ice surface.

The mathematical model is developed in the supposition that pipes with the cooling agent represent *yoz* point sources of heat in the plane the intensity of which changes on the direction of movement of cooling agent flow. If we consider that the heat sources have finite sizes, then the last member in the right part of equation (9.18) should be excluded and the system of equations should be completed with boundary conditions:

$$-\lambda\frac{\partial t}{\partial r} = a_c(t - t^*) \qquad (9.24)$$

As a result, we obtain equation (9.18) in the rectangular system of coordinates and equation (9,24) in the cylindrical system of coordinates. Realization of the mathematical model, the equation of which is written down in different coordinate systems presents certain difficulties. In order to simplify this task, the cylindrical pipes of diameter 2R can be replaced with calculation pipes of square section which perimeter is equal to the depth of the cross section circle of cylindrical pipe. In this connection, the size of sides of square is taken to be equal to: b = 1/2πR. Taking into account the scale, the distance between the centers of the square sections of pipes in the design scheme is equal to the distance between the centers of round sections of pipes in the real rink.

It is expedient to use a finite-difference method for the solution of the obtained equation system, mainly: local – single method allowing to replace initial three-dimensional equation with three single equations, integro-interpolation methods with implicit finite-difference scheme to solve the obtained single equations, and replacement (leveling) of δ-function with δ-form function.

If we accept that the temperature difference of the cooling agent in the entrance and exit of the rink's cooling system doesn't exceed 5-7ºC providing a uniform temperature field on the ice surface, it is possible to consider a task of calculation of the temperature field of the rink construction. Both the pos sibility and expedience of calculation of the temperature field of the rink are discussed in the works of authors [47, 48]. Some of authors proposed the universal method of solving of two dimensional equations of heat conduction and program for computers as well as the recommendations on designing of engineering facilities of artificial rinks [49, 50].

In the practice of exploitation of artificial ice rinks, sometimes ice is used as means for fastening to the surface separate elements made of modern artificial materials suitable for football, track and field athletics. In this case, the task is the determination of thickness of the iced elements and the temperature of their surfaces washed by air should be 5-10ºC. The formula used for determination of thickness of the iced elements can be obtained through the equation of stationary heat conduction for plates on one surface where the temperature t_i (temperature of the ice surface) is preset and heat exchange with the premises takes place on other surface:

$$(t_a - t_s)a_c = (t_a - t_i)/R_0 \tag{9.25}$$

where t_a, t_s, t_i-the temperatures of the internal air, the surface of iced elements washed by internal air and the ice surface; $R_0=1/\alpha+\delta/\lambda$-resistance of heat conduction, ($m^2 \cdot^o$ C)/W; α-coefficient of heat exchange between the surface of the iced elements and internal air, W/($m^2 \cdot {}^oC$) taking into account convective heat exchange between the surface of elements and air and radiant heat exchange between the surfaces of elements and environment; δ-thickness of the iced elements, m; λ-coefficient of heat conduction of the iced elements, W/($m^2 \cdot {}^oC$).

Solving equation (9.25), relatively δ we obtain:

$$\delta = \frac{\lambda}{a_a}\frac{t_s - t_i}{t_a - t_s} \tag{9.26}$$

For example, accepting t_a = 16 °C; t_s 5 °C; t_i = -1 °C; α_a = 9 W/($m^2 \cdot {}^oC$); λ = 0.074 W/($m^2 \cdot {}^oC$)-non woven fiber polyethylene, we obtain δ = 0.0045.

9.2. Temperature regime of the rink with artificial ice

We will consider the temperature regime in the construction of rink with artificial ice on the examples of demonstration and training rinks of the Sport and Concert Palace of Baku n. a. H. Aliyev. Ice is formed on concrete cooling plate, the massive of which is made of monolithic seamless steel pipes. Hydro- and heat- isolating layers, as well as sliding layers are laid under the cooling plates on the foundation. All of them are put on the bearing reinforced concrete foundation. Exploited back office of the Palace is located under the demons tration field, and non-exploited underground is located under training field. A temperature joint protecting the plate against demolition at deformation temperatures is installed around the cooling plate. Heat removal from the cooling plate is designed using intermediate heat carrier with anticorrosion additions (25% solution of calcium chloride with 1,23 kg/l density and 28 °C freezing temperature) cooled in refrigerating station.

Characteristics of the demonstration rink

Size of the ice area, m	*61 x 30*
Temperature of ambient air, °C	*25*
Relative humidity of air , %	*55*

Air motion on ice, m/sec	*≤ 0.2*
Temperature of the ice surface, ºC	*- 6*
Thickness of the ice layer, mm	*40*
Total power of lamps (metal – haloid) in the regime of hockey,kW	*400*
Radiant content of complete heat flow from the lamp, %	*63*

Characteristics of the training rink

Size of ice area, m	*61 x 30*
Size of the cooling plate, m	*61,7 x 31*
Temperature of ambient air , ºC	*22*
Relative humidity of air, %	*up to 50*
Temperature of the ice surface , ºC	*- 4*
Thickness of the ice layer, mm	*60*
Total power of lamps (filament), kW	*175*
Radiant content of complete heat flow from the lamp, %	*42*

The values of specific heat carriers on the ice surface calculated in accordance with the formula stated in section 9.1 are given in table 9.2.

Table 9.2 The values of specific heat carriers on the ice surface

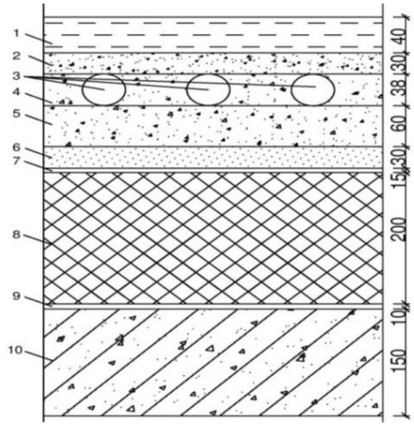
Operation regime	Rink destination	Heat gain, W/m^2
Winter	Demonstration Training	70 60 70 40 240 45 20 55 15 135
Summer	Demonstration Training	100 60 95 100 355 85 20 85 60 250

Also, short-term heat input is considered during processing of the ice surface by combines during intervals between the competitions for the show rink. Heat input entered within 15-20 minutes during processing of ice is commensurable on the value with the quantity of radiant heat and consequently, it is necessary to switch off the main lighting of the arena at that time.

The following dimensions are used in the implemented project: external diameter of cooling pipes of the training rink -32mm *(picture 9.2),* of demonstration rink -38mm (picture 9.3), step of pipes -100mm, internal diameter of collectors -mains for training area -125 mm; concrete layer on cooling pipes -30 mm.

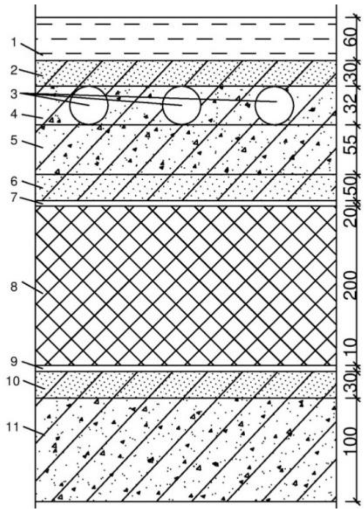
The pipe system of the cooling plate is designed in the form of coils assembled as pairs forming sections, at the same time the input and output areas of coils of each section are located at the opposite sides and are connected accordingly with straight and reverse collector laid on the concrete massive of the cooling plate (collectors are combined with main pipe lines for training area). Such connection of input and output area provides countercurrent movement of heat carrier for each pair of pipes.

Pic. 9.2 A section of the demonstration rink



1 – ice; 2 – cooling reinforced concrete plate (δ = 0,03 m); 3 – pipeline of the cooling agent (d = 0,038 m); 4 – cooling reinforced concrete plate (δ = 0,038 m); 5 - cooling reinforced concrete plate (δ = 0,06 m); 6 – concrete blinding coat; 7- ruberoid and graphite; 8 – bitumen perlite; 9 – ruberoid; 10 – bearing reinforced concrete plate.

Pic. 9.3 A section of the training rink



1 – ice; 2 – cooling reinforced concrete plate (δ = 0,03 m); 3 – pipeline of the cool carriers (d = 0,032 m); 4 – cooling reinforced concrete plate (δ = 0,032 m); 5 - cooling reinforced concrete plate (δ = 0,055 m); 6 – concrete blinding coat; 7- graphite with ruberoid; 8 – bitumen perlite; 9 – ruberoid; 10 – concrete blinding coat; 11- bearing reinforced concrete plate.

In comparison with traditional pipe systems, such kind of pipe system has a number of privileges. Speed of movement of heat carrier in the pipes guaranties the absence of air separation and consequently eliminates the need in multiple devices for its release and also provides good hydraulic durability of the system that allows to refuse the establishment of control valves and simplify the commissioning system.

Placing collectors in the massive of the cooling plate reduces the number of pipelines and conditions minimum number of pipe outputs from the cooling plate into the service corridor that provides the longevity of the construction, while reducing the dimensions of the corridor. Such corridor is not required for the training area.

Temperature differences of the heat carrier at the entrance and exit of the ice rink may reach to 3 ºC (at temperature irregularity on the ice surface not more than 0,5 ºC) and therefore, the amount of circulating heat carrier and consequently electricity consumption of pumps decreases by 2 – 2,5 times.

The character of temperature distribution both on the ice surface and on the depth of the construction up to cooling pipe is shown in pictures 9.4 and 9.5.

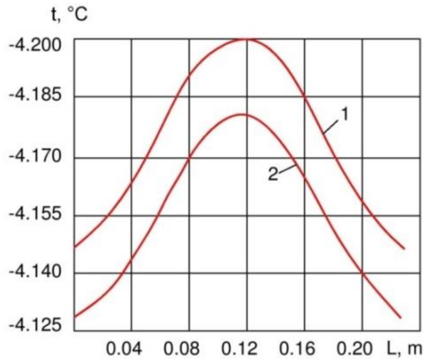
As it is seen from the graphs, the character of temperature variation of the ice surface is sinusoidal. The change of temperature differs insignificantly at the same points of the ice surface during both winter and summer exploitation periods. The minimum temperature of the ice surface is observed on the center of each pipe and the maximum temperature is observed at points equally spaced from two adjacent pipes (table 9.3).

The calculation results allow to conclude:

1. *In order to provide the required temperature of the ice surface (for training rink -4ºC and for demonstration rink -6ºC) the temperature of the cooling agent between the pipes located at a distance of 100 mm should be – 19 or – 21 ºC, respectively.*
2. *Optimal distance between the pipes where $\Delta t \leq 0{,}5$ ºC condition is provided is 100 mm.*
3. *Irregularity of temperature of the ice surface rises with the increase of the distance between the pipes.*

Three low-temperature refrigerating devices were designed for cooling of the demonstration and training ice rinks and two devices together with tank – accumulators were designed for air conditioning systems in the abo-vementioned Sport and Concert Palace. Cooling of ice rinks and water for air conditioning system were designed using intermediate heat carriers-solution of calcium chloride circulated through the piping systems of the rinks and heat exchanger for chilled water. The circulation systems are supplied by joint separated valves with electric drives that allows to use the devices of the air conditioning system for cooling ice fields and the devices of ice fields for the air conditioning system.

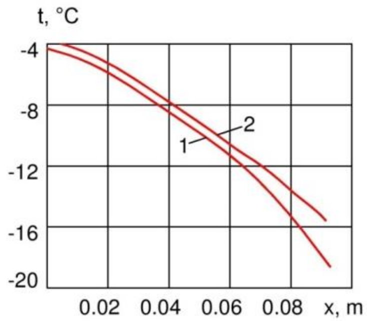
Pic. 9.4 Temperature distribution on the ice surface of the training rink at t_i=22 °C, t_p=19 °C and distance between the pipes 100 mm during exploitation



1. Summer 2. Winter

The total cold need in the air conditioning system comes to 4,1-4,7 MWt. Two devices at 0 °C temperature of heat carrier at the exit from the evaporator can produce nearly 1,2MWt cold. Insufficient part of cold (2,9-3,5MWt) is accumulated in the accumulator when the cooling loads on the air conditioning system are lower than designed load or when conditioners don't work, for example at night. Net capacity of the accumulator is 500 m^2 and it is considered for 17,4 MWt daily load when the temperature of the cooled heat carrier is – 20 °C.

Pic. 9.5 Temperature distribution on the cross section of the training rink at t_i = 22 °C, t_p = 19 °C and distance between the pipes 100 mm during exploitation.



1. on the center of pipe; 2. at equal distance from the centers of two adjacent pipes

Necessary cold consumption during freezing of ice in the demonstration rink consist of the consumption for cooling of heat carriers, cooling plate, rink foundation, formation and overcooling of ice layer with 30 mm thickness totaling 15,5-17,4 MWt. In this case, ice freezing may be implemented using two devices with 366 kW average capacity of each within the freezing time. This time can be reduced to during simultaneous use of ice freezing devices. Besides, there is possibility to use cooled heat carrier accumulated in the tank during freezing and to reduce freezing time on the account of previous cooling of heat carriers, pipes, constructions, i.e. through introduction of refrigerating devices and circulating pipes into the work some hours before the transformation.

Table 9.3 The results of computer calculations of the temperature fields of the training and demonstration rinks of the Sport and Concert Palace of Baku n. a. H. Aliyev

Rink destination	Distance between the pipes, mm	Inside air temperature in the room t_i,°C	Inside air temperature in the cellar, °C		Maximum temperature of the ice surface, t_{is}, °C	Minimum Temperature of the ice surface t_{is}, °C	Temperature of the cooling agent in the pipes, t_p, °C	Maximum unevenness of temperature on the ice surface Δt, °C
			winter	summer				
Training	100	22	10	30	-4,1	-4,2	-19	0,1
Demonstration	100	25	10	30	-6,1	-6,3	-21	0,2
Training	125	22	10	30	-4,1	-4,3	-20	0,2
Demonstration	125	25	10	30	-6,2	-6,5	-22	0,3
Training	150	22	10	30	-4,0	-4,3	-21	0,3
Demonstration	150	25	10	30	-5,7	-6,4	-23	0,7

It should be noted that the cooling plate and the ice frozen on it are comparatively big accumulators of cold that can allow to maintain the ice (for example on the training rink) for some hours when refrigerating devices are switched off. This feature of plate and ice can be used for preventive reparations of the refrigerating devices.

In order to ensure normal operation of devices of ice rinks under freezing regime and sharp change of load the pipelines of warm and cold collectors are connected to the suckers of their circulating pumps which allows to obtain manually the necessary temperature at the exit of evaporator.

The evaporators of the devices are established to be less than required for cooling the rinks amount of leaking heat carrier and designed with four strokes and as a consequence have inadmissible high resistance against the motion of heat carrier. It is necessary to reconstruct the lid of the evaporator for reducing resistance to normal size during installation, wherein the devices become two- stroke.

The scheme of the refrigerating devices provides parallel work of three aggregates in the general collector from which the cooled heat carrier is directed through the straight pipeline to the consumer – demonstration and training rinks. The heated heat carrier comes back through the reverse pipeline to refrigerating station in the collector for the heated heat carrier and then to the evaporator of aggregates. The calculated consumption of heat carriers through the piping constructions of the rinks are different and may be regulated by corresponding valves upon the temperature difference of the heat carrier in the rink and upon the ice temperature that is recommended to make during adjustment of the system. Regulation of temperature of the heat carrier is made in intervals or with activation of compressors. It allows obtaining 60 and 30% complete productivity depending on need directly on the temperature of the ice surface through the sensors measuring ice temperature distantly. Such regulation method allows maintaining the preset temperature of ice and provides minimum electricity consumption. In this case, the consumption of heat carrier through the piping constructions of rinks and aggregates will not change that makes the system hydraulically durable and reliable during exploitation.

Cooling of the condensers of refrigerating devices is implemented by water from the reverse water supply system. Water consumption of all devices is 750m^3/hour at 28ºC temperature (maximum) of water at the entrance to the condenser and 5 ºC temperature difference in the condenser. The cylinder jackets of compressors working at boiling temperature higher than 30ºC are not cooled by water, startup of the compressor is blocked by water flow through the condenser.

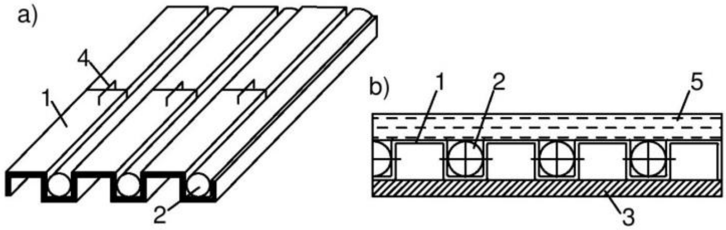
Besides regulation of refrigerating devices productivity upon the temperature of the ice surface, the automated system provides protection against emergency situation and warning lights about the readiness of devices to work and the reason of faults.

Thawing of the demonstration ice rink is realized by the heat carrier with 25-30 ºC temperature. Heating of brine is conducted in water-to-water heat exchanger with hot water received from heat center. The circulation of the heat carrier through the heat exchanger and the pipeline system of the ice rink is realized by auxiliary pump. Both the heat exchanger and pump are installed in the ground floor of the round part of the Sport Palace.

9.3. Temperature regime of the transformable artificial rink with overlaid metallic elements

Transformable artificial rinks are installed in the premises with multipurpose destination. Such kind of premises are used for example as athletics arena in certain period, and as a sports rink in another period. The synthetic coating laid on the asphalt concrete is the floor in the athletics arena. Periodical or seasonal freezing is conducted on special elements (template made of steel with pipes) laid over the synthetic coating. Later, we will call such kind of rink as artificial sports rink with overlaid metallic element. Among the equipments used to freeze the ice floe of movable artificial rink there are plates made of materials with good heat conduction and piping system for passage of the cooling agent attached to the metallic beam of special profile [2] and devices containing metallic panels having heat contact with pipes for circulation of the cooling agent [22]. Relatively heavy load and the difficulties with regard to mounting and processing due to the availability of great number of assembling elements are the shortages of these devices. More perfect devices for freezing ice floes of transformable artificial rinks providing uniform air distribution upon the surface of ice and having simplified mounting system are given in picture 9.6.

Pic. 9.6 A scheme of structure of transformable artificial rink with overlaid metallic elements (a) and fragment of its device (b)



1. metallic panels; 2. circulation pipe; 3. synthetic coating; 4. brackets; 5. ice.

The device is mounted in the following order: metal panels are joined lap in the direction of perpendicular pipes and docked in the longitudinal direction using brackets. Then, the welded into long lashes circulation pipes are laid in the holes of panels.

It is necessary to solve two tasks during heat engineering calculation of the rink with overlaid metallic elements:

1) Determination of the temperature of the cooling agent providing required operating temperature on the ice surface. It is necessary to select such a distance between the pipes the maximum unevenness of temperature on the ice surface does not exceed the rated value, for example 0,25 °C [50].
2) Calculation of the heat isolation thickness of the cooling plate of the rink to protect the underlying layers of soil against frost penetration, as well as against possible heaving and destruction of the foundation of the rink (picture 9.7). Separate elements in the section of the rink have following

heat engineering features: ice δ_i = 0,025 m, λ_i=2,3 W/(m^2 · ºC); air space along OX axis, λ = 2,3 W/(m^2 · ºC); along OY axis, λ = 0,13 W/(m^2 · ºC). Synthetic coating: λ=0,13 W/(m^2·ºC); $\delta_{s.c}$=0,015m; ς=690kg/m^3; C=1,4 kJ /(kg·hour); asphalt concrete λ_{ac}=0,1W/(m^2 ·ºC), δ_{ac}=0.1 m, ς_{ac}=2100 kg/m3, C_{ac}=2kJ/(kg·hour); heat isolation $\lambda_{h.i}$ = 0,19 W/(m^2 · ºC), ς = 600 kg/m^3, C = 0,88 kJ /(kg · hour). Solving of the abovementioned two tasks was implemented under the following simplified assumptions [47]: the pipe is infinitely long cylindrical source of heat in the diameter equal to the external diameter of the pipe; the temperature of the external surface of pipes is equal to the temperature of the cooling mixture t*, as the resistance of heat conduction from the cooling agent against the wall of pipes and thermal resistance of the wall of the metallic pipes is low and it can be neglected; the heat flow entered from the soil to the rink foundation can be neglected. In addition, the boundary conditions on the ice surface given in section 9.1 were considered by the author during calculations.

The following indices are accepted during calculations: overlaid metallic elements-template made of steel with 2mm thickness; the diameter of pipes through which the cooling agent is circulated -32mm; air temperature in the premises - 16 ºC; the temperature of internal surfaces of inclosure -12 ºC; the dimension of premises - 120 x 60 x 12 m, which can accommodate 200 people; the quantity of convective heat entered from lighting sources - 15 kW and radiant – 45 kW; air movement over the ice surface – 0,5 m/sec; the temperature on the ice surface can be -1,5, -2,5, -5 ºC. It is shown in design diagram 9.7 that cylindrical pipes replaced the pipes of square section the perimeter of which is equal to the length of surrounding of the cross section of the cylindrical pipes. The distance between the centers of square sections of pipes in the design diagram is equal to the distance between the centers of round sections of pipes in the real rink. According to previously accepted assumptions, the heat flows q_x through the boundaries of the area (AB, СД, EF, KL) and q_y through BC area are equal to zero.

Calculations of two-dimensional temperature fields of the rink construction with overlaid metallic elements were implemented using computer program [49].

The following parameters varied during calculations for determination of optimal features of the rink with overlaid metallic elements: distance between the pipes -f, thickness of the synthetic coating –$\delta_{s.c.,}$ temperature on the ice surface -$t_{i,}$ coefficient of heat conduction of the interlayer between pipes – $\lambda_{i.p.}$ (the possibility of filling the air space with heat isolation material was considered). The results of the calculations on different versions are given in table 9.4.

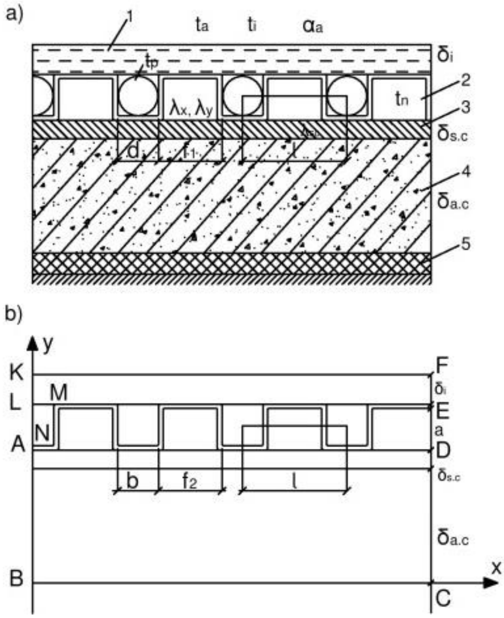
The temperature of the ice surface changes sinusoidally. The point of minimum value– t'_l is located under the center of each pipe, maximum temperature of ice– t''_l is stated at the point equidistant from the adjacent pipes. Temperature difference $\Delta t_l = t''_l - t'_l$ is called as maximum irregularity of temperature of the ice surface.

Analyzing table 9.4 we can come to the following conclusion:

1. *In order to achieve operating temperatures (maximal) on the ice surface of the rink with overlaid metallic elements t'_l equal to -1,5, - 2,5 and - 5 °C the temperature of the cooling mixture in the pipe should have – 5, -6 and – 8,5 °C, respectively (when f_1= 5 mm, d = 32 mm).*
2. *Optimal distance between pipes equals to 5 mm when Δt_l < 0,25 °C condition is provided.*
3. *The temperature of the cooling mixture in pipes t_p should be decreased by 0,5°C for obtaining preset operating temperature on the ice surface when the temperature of the internal air in the premises increases by 4°C (from 16 to 20 °C).*
4. *Maximum irregularity of temperature on the ice surface Δt_l increases with the increase of air temperature in the premises and the distance between the pipes f_1.*
5. *Filling the air spaces between the pipes with heat isolation materials [poly urethane foam q=75 kg/m^3, λ=0,046 W/(m^2·°C)] doesn't give any thermo technical effect.*
6. *Reducing the thickness of the synthetic coating nearly twice (from 1,5 to 0,8 mm) doesn't practically change the temperature field in the area of overlaid metallic element of the artificial rink.*

Calculation was made for determination of quasi-stationary temperature field of the rink foundation as well as the temperature field of soil under the rink foundation. Following conditions were accepted during calculations: heat isolation layer-ceramsite gravel. Arena was used under the rink within 5 months, for athletics competitions within 7 months; soil under the foundation – dusty loam capable of strong heaving [λ= 1,6 W/(m^2·°C); q =1600 kg/m^3] and the temperatures of the ice surface -5°C and cooling agent – 9°C. The results of the calculation of the temperature field of the rink and soil under it showed that the use of heat isolation layer with 0,4 m thickness under the rink foundation excludes freezing of soil.

Pic. 9.7 Section of the rink with overlaid metallic elements (a) and its design diagram (b)



1. ice; 2. air space between the pipes; 3. synthetic coating (rubber crumb on the base of synthetic binder); 4. asphalt concrete; 5. heat isolation (ceramsite gravel).

Table 9.4 Results of calculation of the temperature regime of the construction with transformable artificial ice

The thickness of the synthetic coating	The distance between the pipes	Internal temperature	Thermal conductivity of the layer between the pipes	The maximum temperature of the ice surface	Temperature of the cooling tubes in the mixture	Maximum temperature unevenness on the surface
0,015	0,05	16	$\frac{0,023}{0,11}$	-1,5	-5	0,21
0,015	0,05	16	$\frac{0,023}{0,13}$	-2,5	-6	0,23
0,015	0,05	16	$\frac{0,023}{0,13}$	-5	-8,5	0,25
0,015	0,05	16	$\frac{0,046}{0,046}$	-1,5	-5	0,21
0,015	0,05	16	$\frac{0,046}{0,046}$	-5	-8,5	0,25
0,015	0,10	16	$\frac{0,023}{0,13}$	-5	-8,5	1,2
0,008	0,05	16	$\frac{0,023}{0,13}$	-5	-8,5	0,25
0,015	0,07	16	$\frac{0,023}{0,13}$	-1,5	-5,2	0,5
0,015	0,07	16	$\frac{0,023}{0,13}$	-5	-8,8	0,6
0,015	0,05	20	$\frac{0,23}{0,13}$	-1,5	-5,1	0,32
0,015	0,05	20	$\frac{0,023}{0,13}$	-5	-9	0,34
0,015	0,07	20	$\frac{0,023}{0,13}$	-5	-9,3	0,7

10. THE USE OF SOLAR RADIATION FOR REDUCING THE ENERGY CONSUMPTION OF SPORTS FACILITIES EXPLOITATION

The use of solar energy attracts great attention, first of all because of ecological cleanness of this source, and secondly, because of practical inexhaus tibility. About 5,5 $\cdot 10^{24}$ J energy falls on the Earth over a year. The task is in intercepting this great energy flow and enforcing its some part to work for people before being dispersed and reflected in the space. The efficiency of this energy source depends on the geographic location and climate conditions of the territory.

The ways and methods of the solar energy use are extremely diverse. Photovoltaic batteries, water heaters, heating devices and conditioners and high-temperature stoves should be mentioned as principals among them [51, 52].

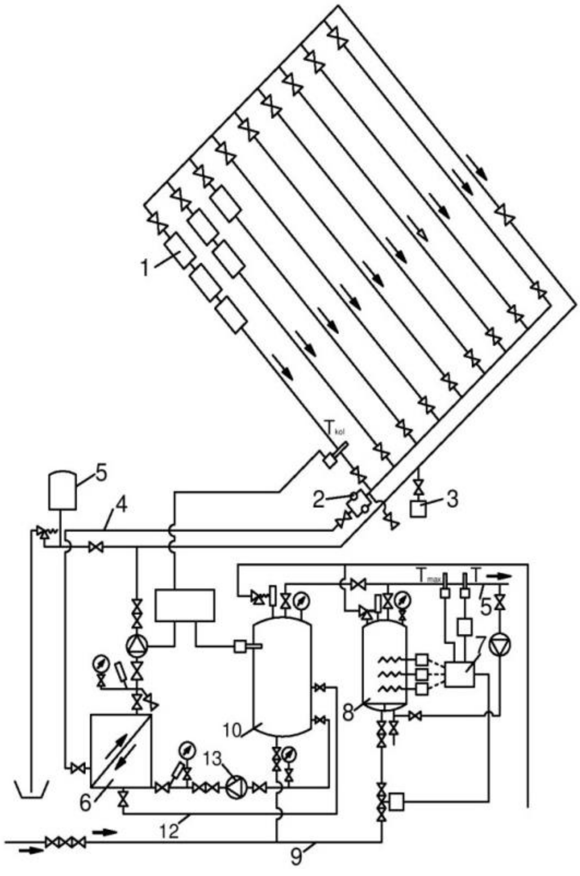
Hot water supply and heating are the simplest methods of direct use of solar energy (picture 10.1).

Despite the fact that Azerbaijan is located far from the equator, considerable part of solar radiation falls to its share. Minor cloudiness, remoteness from oceans and protection by mountain ranges makes feasible the use of solar energy in a number of regions of Azerbaijan. The researches have shown that the use of solar energy in Azerbaijan will be economically viable in the future [53].

Indeed, it would be unreasonable to try to use energy of sun beams without taking into account concrete conditions. Meteorological factors of this territory including temperature variation, precipitations, number of solar days in a year and their duration, direction and speed of predominating winds in the territory and also the remoteness some residential areas from other energy sources, the cost of fuel and its transportation, as the specific requirements imposed by the exploitation of heated premises and facilities – all of them complicate the problem of expediency and efficiency of attempts to use the energy of sun beams.

The issues of the reliability of climatic data and safety of forecasted thermal and other parameters of facilities under construction are drastic while using new natural energy sources such as solar energy. Unreliability of calculations may lead to the necessity of installation of auxiliary and backup plants for heating, ventilation and air conditioning based on traditional energy sources together with solar power plant. All of it leads to significant rise in the cost of construction, which in its turn, increases the request on durability of design and is often justified. Even when the main contribution to power system of the sports facilities is electricity and fuel, and solar station is auxiliary functioning only under favorable conditions of energy sources, essential benefits can be obtained taking into account the scales of power consumption by sports complexes.

Pic. 10.1 Schematic diagram of hot water supply system using solar collectors



1. solar collectors; 2. air valves; 3. tank; 4. pipeline of the system of solar collectors; 5. capacity for compensation of liquid expansion; 6. heat exchanger with countercurrent diagram; 7. three – stage switch of heater elements; 8. water heater with electric elements; 9. pipeline of cold water; 10. tanks with water for domestic needs; 11. temperature regulator; 12. pipeline of hot water; 13. pump for hot water circulation; 14. pump for circulation of fluid the solar collectors' circuit.

As a result of the researches implemented by the author, it was ascertained that heat consumption for indoor swimming pool in Tashkent city is distributed in the following manner: 56,5% for hot water supply, 25,4 % for ventilation and 18,1 % for heating. It is obvious that the simplest realized purpose of solar power plant-the heating is not the principal energy consumer. Since the major part of energy consumption of the open and indoor swimming pools falls to the share of hot water supply, it is expedient to use solar energy for year – round heating of water (with fuel alternate) in indoor swimming pool and for seasonal heating in open swimming pool. It is necessary to take into account the kind of the swimming pool (open, covered and complex), its orientation, assignment of the premises and bathes, volumes of halls and etc. while calculating the area of solar plants and selecting their types.

It is especially expedient to use solar energy for air conditioning in premises, as maximum need is observed in the period when more energy of sun beams enters. However, thermodynamic limitation restrains effective use of solar energy for air conditioning in premises. Economic indicators of the installation of air conditioners working on solar energy will not be satisfactory on average in seasonal load.

Other seasonal load for solar power plant is air heating in the premises. However it doesn't coincide with the period of solar energy entrance. If the system must satisfy significant need for heating in winter, large areas is required of solar energy collectors.

It is known for a long time that interseasonal accumulation of energy significantly increases the possibility of heating the premises using solar energy. However, high cost of accumulators and difficultly satisfied demand in area are the main reasons hindering solar energy use up to the present time.

Of course, the specified difficulties and uncertainties are explained by newness of the problem and the lack of necessary experience on designing and exploitation of solar systems. Though that the first successful practices on the solar energy use for heating were implemented long ago, at least two centuries ago, in any way, industrial and scientific perfection of the problem is a matter of the future.

The solar radiation splits into three main parts when it enters into the earth atmosphere. One of them is absorbed by vapors of water and ozone and the second part is dissipated with molecules of air and vapor and dust particles (diffusive); the third part reaches the earth surface without entering into interaction with atmosphere (direct radiation). Complete solar energy fallen on the earth surface is the sum of direct and diffuse radiation. There are a number of simple empiric formula [54] for the calculation of surface intensity of the radiation depending on the height above the sea level, angle of slope of beams to horizon, orientation of the radiated surface towards the Sun and etc.

When the sun beams fall on any surface, then its temperature rises in comparison with ambient air. This temperature rise is the result of accumulation of heat on the surface due to absorption of the sun beams energy. If to construct a tank in which water will be circulated under heated surface, then the latter will be heated too. This is the simplest device for use of solar energy and the necessary equipment will be the most primitive. The simplest and oldest installation for water heating is of the type of "hot box", one of the first such kind of installations was developed by Goratsie Sossure in 1770.

The principle of its work consists of the fact that the sun beams freely pass through the glass closing the box excluding ultraviolet and infrared parts of specter. The sun beams entered into the box are absorbed by non-transparent internal surfaces and heat it. In their turn, the heated surfaces begin to radiate inversely received heat with a capacity proportional to the fourth degree of temperature. However, this long wavelength radiation from low temperature source doesn't pass though the glass enclosing box. Thereby, "hot box" is the trap for solar heat.

At present, commercially profitable installations are not so simple. How ever, they are constructed on the same principle, though that they have much greater efficiency.

Modern solar generator of hot water consists of two main parts: solar collector and tank with hot water. The surface of the collector can heat water from 50 to 80 ºC. Temperature reaches 300-350ºC in the vacuum collectors with ideal surface. The use of parabolic radiation concentrators allows to obtain higher temperatures.

The water heated by the Sun enters from the collector at the temperature 55 ºC to the heat exchanger of the solar tank where amount of water necessary for consumption is accumulated. Circulation of heated water can occur accor ding to thermosyphon principle or by means of pumps and their work is controlled by the thermostat installed on the upper layer of the collector. The latter can be combined in a chain and daily water rate will be increased in this case. Heat isolated tanks with hot water are installed in the roof or in the basements.

Let's consider the main elements of modern solar installation and solar collectors, solar energy accumulators and heat transfer system more detail.

Solar collectors shall gather heat from sun beams with maximum efficiency. There are various types of collectors differing with the form of external surfaces, installations of absorbing surfaces and accumulating environments under significant variety of local conditions and tasks of solar station. In any way, it is possible to distinguish two main types of collectors: concentrators focusing radiation and flat collectors.

Focusing collectors have concave surface. They concentrate sun beams with glasses or lenses. 200–500 ºC temperature can be obtained by low con centrations of the order of one to ten. Temperature up to four thousand Celsius can be reached under higher concentration of beams.

Large concentrators of radiation are installed in many countries and are often used in heavy industry and research works. For example, solar heating in Pyrenees in France has the system of parabolic glasses of 40 m height and 54 m width with focusing distance 18,4 m., wherein 4000 ºC is reached. The maximum thermal power of the installation equal to 200 kW is used for experiments on swimming.

Radiation concentrators usually use only direct radiation, but the researches of the last years show that notwithstanding these features, such kind of collectors can be used under moderate climatic conditions for getting hot water and vapor.

Mirror collectors shall be located under constant control, as they are very sensible to contamination with dust and debris, which sharply decrease their optic qualities. The mirror can be protected against the influence of weather conditions by glass coating, but differing from the surface collectors, mirror should be cleaned very often so that not to weaken the radiation with additional dispersion. Under desert conditions or in the neighborhood with big industrial centers, the pollution speed of the surface can be great. It is difficult to mechanize the cleaning work, but certainly, it is not desirable that the effi ciency of solar station depends on the efforts of cleaners.

Other shortage of concentrating solar collectors is unavoidable significant daily temperature drops in the materials of the facility conditioned by high temperature in active period. It requires using special materials that increases the cost of the installation.

The solar collector of focusing type constructed by the firm "Phillips" is supplied with warm reflecting filter with indium oxide and capable of absorbing solar radiation up to 95% [55]. Experimental researches on such kind of collector under conditions from clear cloudless sky to completely cloudy summer (in general radiation from 800 to 150 W/m^2) give 60-20% efficiency.

Focusing solar collectors should be supplied with automatic Sun tracking system to work effectively and it doesn't concern their privileges. Further exploitation will show which of suggested and already realized types of solar collectors of focusing type is more efficient.

Flat collectors of solar energy are similar for many features with the collectors of "hot box" type described above, their work is based on greenhouse effect. Flat collectors consist of wooden, plastic or glass structure supplied with transparent coating, absorbing surface, isolation and heat transfer means which mainly consist of air, water and oil. Transparent coatings are usually single, double or triple and made of plastic or glass. Absorbing surfaces can be selective or non – selective.

Experimental study of characteristic features of the selective external surfaces allowed to determine optimal combination of two thin layers of the transparent coating which provides 94 % absorption of solar radiation at 6% emission [55]. All elements of the plate collector together form installation for absorbing solar radiation which is cooled by heat transfer means.

The materials used for isolation should have minor heat capacity and lower heat production as possible. The operating temperature of the collector should be achieved within the shortest possible time during short period of solar radiation. External surface of heat isolation must be resistant under any atmosphere condition.

Flat solar collectors decrease their efficiency when the transparent coatings are polluted and shaded from the racks and frame jumpers or reflected from glass surfaces as well as due to the heat passing through glasses. The ratio between the radiation energy and useful thermal productivity determines the efficiency of the collector.

The highest temperature produced be the collector is achieved when the additional useful heat doesn't go away through heat transfer means, i.e. when the obtained radiation energy is equal to the losses of the collector and plus involved useful heat. In this case, the collector works on its heating without passing heat to the consumer. Such maximum achieved temperature is called unproductive or balanced temperature. Different balanced temperatures correspond to the design and the quality of the collector, radiation intensity and environmental conditions. For example, the solar radiation about 900 W/m^2 can be considered as normal under the European conditions. Under this radiation, a collector with single glazing can produce temperature up to 100 ºC and a collector with triple glazing can produce temperature up to 190 ºC.

It is possible to increase the efficiency of planar solar collector due to special processing of glass coating, panels and sheet material of absorbed materials. A solar collector with 70 % efficiency can be considered as normal for usual low temperature level.

The absorbing surfaces of installation have dimensions depending on how much heat is required, how the sports facility is designed and how it is oriented towards the Sun, and also on geographical and climatic conditions. In order to assess the order of magnitude it should be noted that a collector with 7-10m^2 area is enough for hot water supply per a family under climatic conditions of Central Europe in case if the storage of corresponding amount of energy in heat accumulator is possible.

Optimal slope of the planar solar collector relative to the horizon depends on whether the solar station works in summer or winter and how its position changes with respect to the horizon, for example from 10 to 15 º. Certainly, these figures depend on the latitude of the territory, however, it is necessary to state that the range of angle variation is not great and it can sometimes be neglected. Besides, the change of angle is seasonal in nature and not permanent, as in the case of focusing collectors does not require the use of automation in the case of focusing collectors doesn’t require mandatory application of automation.

Planar solar collectors have some disadvantages including: overheating, freezing danger of the cooling fluid in winter, corrosion, pollution and damage due to thermal expansion or constriction. Their influence can be changed depending on climatic conditions and the means for their elimination varies from one model to another.

Usually, the solar heat is quite enough for that season when heating is required least of all, and it is required at a certain time (i.e. in the day time). It can be insufficient at night time and in cold season of year. The maximum heating demand is observed in the months when daily solar radiation continues only for some hours. Thereby, in order to use solar energy when it is needed it should not be only collected, but also stored.

Accumulators of the solar stations’ heat serve for this purpose. The use of the solar heating system with short term storage of energy means that 50 -70% of this energy can be saved depending on both the climatic conditions and engineering constructions. The excess heat energy stored for a long time in summer period should be reserved till winter that is more difficult task.

Heat accumulators can reserve energy both in the form of kinetic energy of the molecule of substances and in the form of the latent heat of phase transitions, for example, melting or evaporation. In most countries water is the cheapest mean of accumulation. Many specialists consider hot water as better environment for preservation of heat, though corrosion problems cause certain difficulties. Water reservoirs must be well isolated in order to reduce the heat losses.

A temperature interval within which water can be used for heating is from 60-80 ºC to 4 ºC. In the practice, dwelling house with a 200 m^3 volume of hot water reservoir can reserve enough amount of the energy accumulated in summer till winter, while using additional entrance of heat from collector to accumulator during autumn, winter and spring times.

Heat loss from the accumulator is determined by the quality of heat iso lation and volume, form and temperature of the reservoir. It is possible to use small, but well isolated reservoir or large accumulator with higher heat loss. Optimal solution of the problem is determined by both the cost of the accumulator and the cost of its exploitation. The followings are the most important factors: the cost of 1 m^3 of the accumulator, the cost of 1m^2 of the isolation, minimum permissible temperature, temperature drops of the accumulator and the environment and work duration of the accumulator.

Besides water accumulators, there are the accumulators containing together with water pebbles or stones and also the accumulators containing pebbles, stone or crushed stones without water. However, accumulators without water need large tanks due to the fact that usual flat solar collector works with relatively low temperatures and higher temperature is needed for effective use of accumulators with stone filling. At the same time, heat transfer into them is unusually easy: air enters directly into the accumulators with solid material through stone layers or through pipeline in the concrete reservoir and is heated or cooled.

Besides already described heat accumulators, chemical accumulators are very promising. The system of solar accumulator using the Glauber's salt was developed at USA Delaware University in 1944. Glauber's salt is capable of accumulating at least eight times more heat than the same water volume under the temperature variation from 27 to 38 ºC. Glauber's salt melts at 38 ºC, so heat is accumulated not only due to the heat capacity and also due to the phase transfer–melting. This heat is produced during the cooling and solidification. The cost of such kind of accumulators is higher than the cost of water accumulators, but the saving is achieved due to the volume and isolation materials. Furthermore, Glauber's salt is not consumed during the accumulator exploitation.

Along with the Glauber's salt, other chemical substances can be used in accumulators. For example, the company "Phillips" used tetroxide potassium fluoride for investigations. Also, different organic combinations, especially paraffin can be used as materials accumulating heat due to the phase passages.

Chemical accumulators are characterized by large quantity of heat reserve per unit volume, good heat conduction during loading and unloading, small volume changes, chemical durability, low corrosiveness and cost. Many specialists consider that chemical accumulators will be used in the future, but time will show which accumulation system of the solar heat will be the best.

The possibility of solar energy use for cooling and air conditioning purposes is less obvious in comparison with heating, though the experience derived from construction shows that thoroughly developed design of the sports facilities can make the use of cooling device unnecessary under normal climatic conditions in most of the regions of Azerbaijan. In case if air conditioning is needed, the solar energy can be used, as far as the solar radiation is maximally available during hot days when cooling is necessary.

Indoor air can be cooled through the solar heat using simple natural processes, for example, due to liquid evaporation. One of the simple methods is the installation of reservoirs with a layer of water of several tens of centimeters on the roof which is covered by heavy polyurethane plate during the day that prevents passing direct solar radiation. The water cooled by this way on the roof cools the room through the ceiling. The main problem is the high cost and scarcity of water in the hot areas where conditioner is necessary.

Another possible method of cooling of the premises is the use of reverse greenhouse effect. In this case, direct solar radiation is decreased through the orientation of facilities and natural reverse radiation is increased. Also, transparent surfaces for thermal radiation and reflecting materials (aluminum, glass, water and plastic) are used on the housetops and walls.

Solar collectors of focusing type are often used for the generation of energy which is used for actuation of cooling devices.

It is necessary to state that there is no details for effective solution of the problems of conditioning: even use of special sun reflecting paint can provide temperature drop of the surface from 60 to 20 – 25 ºC [56].

The above considered problems and their solution methods concerned both the use of solar energy in households, and in administrative, scientific, production, cultural and sports facilities. A number of specific features occur during consideration of the problem of solar heat use with regard to sports objects. It is related with the large size of sports facilities, specificity of their occupancy during day and night times, complexity of the facility, when courts, closed halls, arenas, indoor and open swimming pools are combined in one center. Dressing and shower rooms where hot water supply is always needed are indispensable attributes of sports facilities. People don't engage in sports with outerwear, therefore, the issues related to comfort, conditioning and ventilation play principal role especially when responsible competitions are planned.

On the other hand, sports complexes are not used for dwelling purposes and it is necessary to satisfy required conditions only in working hours allowing decrease of comfort in idle hours. It is easier and cheaper to use scale industrial methods of solution of issues on heating, conditioning and hot water supply in large sports facilities. Such kind of large facilities are designed in detail. Various computer programs are used for their modeling and calculations.

Specificity of sports facilities directly influence the architectural planning and constructive designing of the swimming pools, sports halls and other facilities where solar heat collectors are used as shaping elements of architecture (wall, roof-wall, shading sheds and solar protection devices). Solar receivers with 50 m^2 area are used for the shower-baths of sleeping complexes and dressing rooms mounted in the shading hovel of the exploited roof of the building [56].

Frequent disposition of solar collectors on the roof of sports complexes and pavilions is used if the foreign practice of sports facilities designing. A solar collector of 600 m^2 area was mounted in the southern slope of the roof of the sport complex in Saint Clara (California, USA). This installation meets 65% of energy consumption for air conditioning in summer and 84% demand for heating and hot water supply totaling 75% of all energy consumption of the building.

Alone standing solar installations are used frequently as sports complexes usually occupy vast area with many sports paths, squares and so on. Successful example of alone standing solar station is represented by the sports complex in resort center of Vill in Koln city (Germany). The sports complex consists of the building of multi-objective assignment used as gym or indoor artificial rink, open swimming pools, football – track and field areas.

One or several swimming pools are frequent attributes of the sports complex. On the one hand, this increases concern for maintaining comfort conditions in the sports complex, on the other hand it allows using them as natural heat accumulators for solar station as the heat capacity of large water tanks is very high.

Great practice is derived from the use of solar heating of large swimming pools of sports complexes. Solar collectors are usually made of plane type and installed on the roof of indoor swimming pools. The water pumped from the pool and returns back after heating.

Great heat losses from the water surface are the main problem of open swimming pools. One of the methods of reducing heat losses is closing of the pool during downtime with big plastic shield which let the solar radiation pass at the same time preserving the heat. But, such kind of methods requires special mechanisms. Solar collectors for open swimming pools can be mounted on the walls, sheds and turbines or located outside the pool construction. In this case, the area of collectors increases compared to the area of indoor pools.

It is necessary to state that there is no doubt about perspective of solar energy use for heating, air conditioning and solution of other problems while constructing sports complexes. The problem is only in the term of transition to this new energy type, rationality of selection of the engineering solutions and also in necessity of the duplicating usual energy sources.

11. HEAT PUMP SYSTEMS FOR HEATING AND COOLING OF SPORTS FACILITIES

Direct use of solar energy is complicated with low coefficient of efficiency, short life and high cost of solar installations. Non-coincidence of the peak loads of solar systems with solar radiation intensity both within a day and year is also an essential shortage. Moreover, it is necessary to take into account the stochastic character of climatic conditions.

The abovementioned shortages are significantly eliminated while using heat pump system for heating and cooling of buildings, transforming the low -potential solar energy accumulated by soil or ground waters of upper layers of the earth into high-capacity energy which can be used directly for heat supply. Wherein, ground actually serves as a heat accumulator with non-limited capacity collecting and storing of solar energy. There are layers of ground located in some depth which are not practically damaged by seasonal temperature fluctuations. The accumulation depth of these layers changes depending on soil-climatic conditions of the territory within some meters.

The daily temperature fluctuations of external air influence the surface layers of soil up to several tens centimeters. The temperature of the ground located below this layer changes within insignificant limits lower than 5 ^{o}C.

The temperatures of different soil layers fluctuate on time, and period of these fluctuations coincides with daily and yearly periods of the external air temperature fluctuations. But, amplitude and phase of these fluctuations strongly depends on bedding depth of the ground layers.

Amplitude of fluctuations declines with the increase of depth, and the time lag from the external air fluctuations increases. Maximum temperatures of soil are observed at several depths in colder period of year.

In order to use the thermal energy of the Sun accumulated in soil a register of pipes with circulating heat carrier is installed in the ground. Taking heat from the soil the register passes it to consumers. Availability of ground waters in the little depth of soil sharply increases the productivity of heat collection system, as washing with ground waters provides constant heat inflow to the register. In addition, soil humidity increases its heat conduction and improves the contact of soil with pipes.

The heat accumulating feature of the ground massive allows cooling down the heat carrier flowing through the register pipeline that is used for air con ditioning within the hot period.

The device taking the heat of the heat carrier entered from the register pipes at several degrees and transferring it to the heating system at several tens degrees is called heat pump. It is a device, but it looks like a refrigerator according to its working principle and is, in the main, a heat machine with reversible cycle.

Four types of heat pumps have been developed and used: compressor pump, jet pump, absorptive pump and thermoelectric pump. Compressor heat pumps have comparatively high efficiency and small dimensions. High cost and complicacy of manufacture, as well as high consumption of the mechanical energy under significant increase of vapor tension are the main shortages of these pumps. The field of application of these heat pumps is the installations of high productivity with small pressure rise.

Production and service of jet heat pumps (jet compressors) are simple, they are very compact and cheap. Low efficiency (nearly 20-25%) that is worsened during the work of the compressor under the regimes differing from designed conditions is the disadvantage of the jet pump.

Absorptive heat pumps have high coefficient of efficiency. These devices have no movable parts and can be easily manufactured. However, great specific metal expenditures make them bulky. Since metals are capable of corrosion, the use of alloyed steel is necessary. Moreover, circulating alkali solution complicates the exploitation conditions.

Thermoelectric solar pumps are designed on the bases of use of new materials. They don't have high coefficient of efficiency and have significant specific dimensions. At the same time, these pumps are durable.

As a whole, it is possible to consider that compressor heat pumps have been widely spread.

The working principle of heat pump was described by the English physic Kelvin in 1852. According to the second thermodynamic law, heat transition from less heated body to more heated body is possible only in additional work input or heat from outside and is implemented by means of implemen tation of reverse circular thermo-dynamical process (cycle). The most perfect circle for transition of heat from one temperature level to another is Carnot cycle.

Adiabatic compression in Carnot circle is realized in the compressor by work input and expanding in the gas expansion machine – by obtaining of work. During consideration of the work it is considered ideal, i.e. supposed that there is no mechanical losses during friction and no heat losses through walls and so on.

The efficiency of the cooling cycle is determined by the cooling coefficient ε, i.e. the ratio of the heat released from cooled body to the work input into the cycle. For Carnot cycle the cooling coefficient is equal to:

$$\epsilon = T_0/(T_H - T_0)$$

where T_0 and T_H - substance of the temperature in absolute scale of temperatures in accordance with cooled and heated environments.

It is seen from this expression that cooling coefficient doesn't depend on the features of the agent and is determined only by the temperatures of the environment. Increase of T_0 and decrease of difference between T_0 and T_H raises the cooling coefficient and consequently, energetic efficiency of work of the installation.

The heat pump works analogically with the cooling installation, but its efficiency is characterized by the coefficient of transformation μ, i.e. the ratio of the heat received by the heated body with T_H temperature to the mechanical work input in the installation, i.e.:

$$\mu = \frac{T_H}{T_H - T_0} = 1 + \epsilon$$

In the real installations these coefficients are lower than in the idealized conditions of Carnot circle. However, dependence on temperature fall of the operating environment T_0 and T_H remains higher. For example, if the external temperature is equal to 0°C and the internal temperature is equal to 25 0°C, then the real coefficient of transformation μ will be lower than its theoretically possible value. Its value is lower in practice.

Let's cite the house having a total area of 150m^3 built in 1982 in settlement Bulduri of Latvia as an example illustrating the above described ideas on the use of low temperature of the earth and ground waters. The house has span roof of attic floor. The walls are made of two layers of flake boards with 1,5 cm thickness, a layer of glass wool is put between them. The window has double glazing. Heat consumption for heating of the house is 90 W per 1 m^2 area.

Solar heat accumulated in the soil and ground waters is collected from the area of 400 m^2 (20 x 20 m) in front of the house. Heat collection system is a polyethylene pipeline of 40 mm diameter and 410 m length. It is laid at a 90 cm depth of soil. The depth of the pipeline is determined by the availability of non-freezing ground waters at a depth of nearly 80 cm.

The heat carrier-antifreeze is circulated through the pipeline. Its temperature is lower than the temperature of the surrounding soil due to which heat removal happens.

After heating in pipeline, the heat carrier enters into the evaporator of the heat pump and gives heat to the heat carrier of the second contour which evaporates. Freon is chosen as the heat carrier of the second contour. Its vapor is absorbed from the evaporator and compressed by the compressor and enters to the condenser, wherein the temperature and pressure of vapor increase. The cooled waste antifreeze from the evaporator of the heat pump enters again into the pipeline of the heat collection system.

At the same time, the freon vapors in the condenser give their heat to water and compressed due to the elevated temperature. The compressed freon returns back to the evaporator through the expanded valve.

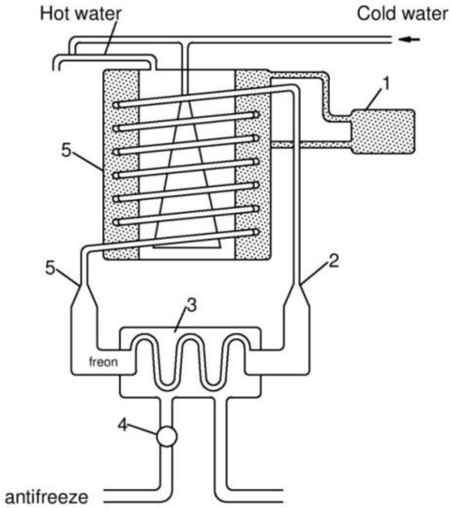
The water heated in the condenser enters to the hot water supply system and the radiator of the heating system. There is a tank with 320 l capacity which supplies the building with hot water of 60 ºC temperature.

The circulation pumps of the installation and compressor work with electrical energy. The coefficient of heat transformation of the installation representing the ratio of the received useful thermal energy to the energy consumed for the operation and is equal to 3.0 according to the data of the house constructed by the Swedish firm AGA. The capacity of the thermal pump installation is 7,5 kW (picture 11.1). We should notice that for the given conditions, the maximum achievable under ideal conditions of Cornet circle coefficient would be equal to 5,6.

The results of experimental natural in-situ researches of this installation in Latvia during the heating period showed that the coefficient of heat transformation was equal to 2,7, i.e. 2,7kW heat power was obtained at 1kW consumption. According to the preliminary data, the annual consumption of electric power of the heat pump installation is 1,75t of the conditional fuel or 14240 kW·hour. In-situ researches showed that the installation has completely met the building requirements for heat and hot water, air temperature in the dwelling premises of the experimental house didn't fall lower than 17 ºC.

The installation is provided with automatic regulation system to support the temperature in the heated rooms within predetermined limits. Automatic regulation system includes internal meteo-sensor and sensor of water parameters installed at the entrance of the radiator network which shall maintain 50ºC temperature in radiators. These sensors regulate the work of the installation in accordance with external climatic conditions. The installation is supplied with the program for different seasons of year controlling the work of the circulating pump of the heat carrier, compressor and circulating pump of the radiator network and additional daily and weekly programs with individual regulation allowing to change the temperature in the premises, when necessary.

Pic. 11.1 A principle scheme of the heat pump installation of AGA firm



1. radiator; 2. compressor; 3. evaporator; 4. circulating pump; 5. expanding valve; 6. condenser – air heater

In case, if the heat is not taken from the heat carrier, the temperature of the heat carrier in the ground heat exchanger remains constant within the level of 12 – 13 ºC, at the same time, significant daily changes happen in the external air temperature ranging up to 15 ºC.

Under the heating regime when the heat pump is working, the temperature of the heat carrier did not change over the research period and was equal to 5ºC in the entrance of the ground heat exchanger and 8ºC in its exit. It allowed to use water instead of antifreeze.

The temperature of air entering to the premises through the heat pump condenser was 35ºC and the inside temperature was not lower than 20ºC during night time when the temperature of the external air equaled to – 6 ºC.

The capacity of compressor was about 0,8 kW, the overall efficiency of all installations was nearly 35% and the heat productivity was approximately 2, 5kW. Thereby, the coefficient of heat formation was 3-3,9 and specific heat removal with1meter of pipe of the soil heat collector was equal to 6,3 W/m.

It is necessary to state, that it is possible to use this installation both under the heating and the conditioning regimes making insignificant changes through four-way electromagnetic valve installation.

Interesting sample of use of low-temperature heat of atmosphere and atmospheric precipitations is elaborated by the Germany firm "Zeeman". In this design, the heat carrier (antifreeze) passes through the system of plastic pipes laid in the concrete elements of the building's enclosure. Antifreeze absorbs the heat from concrete walls and transports it to the heat pump. High heat conduction and heat capacity of the reinforced concrete provide good transfer of heat to the heat carrier. The reinforced concrete construction is painted in dark color that facilitates the use of not only the atmosphere heat, but also the energy of direct sun beams. Besides walls, the fences, balconies and decorative panels, etc. can be used as the constructions absorbing heat.

The heat supply system is equipped with thermal accumulator working at 0 to 10 ºC temperature and the concrete plates of the fundament with plastic pipes laid inside them can be used for this purpose. Its heat losses are negligible, moreover, soil massive can heat it itself due to the fact that the heat accumulator works at low temperatures.

Let's notice that natural heat losses of the heated rooms are caught inside the wall by the pipeline of the heat collection system and are used for heating antifreeze. According to the data provided by firm "Zeeman", the heat balance of the unit area of wall is as following: 87W/m^2 enters from the environment, 13 W/m^2 from the heated premises. Totally, 100W of the heat energy falls to 1 m^2 absorber area when the temperature of the external air is 0 ºC and temperature inside the premises is 20 ºC. According to the data of the firm, the considered heat supply system allowed to reduce twice the cost of heating of 32 apartments.

The use of heat pumps as auxiliary means for the heating of premises together with the installations designed to directly use the energy of sun beams for heating is described in a number of works. Probability character of the climatic phenomena doesn't allow to supply the necessary amount of heat from such installations with certain reliability, therefore, it is always necessary to have reserved free sources (as a rule, electric heaters, rarely stoves and heaters) of heat when they are used. As we discussed above, the use of heat pumps instead of usual heaters allows using the electrical energy more effectively. Heat pumps supply 30-35% energy in the energetic balance of the heated object depending on the probability of frequencies of interruptions during the work of the direct solar heater. Coefficient of transformation of the heat pumps is equal to 2 – 4.

It is not necessary to think that the work of heat pump is always associated with emission of heat only from low temperature absorbers of the solar radiation.

Removal of heat from them is impossible without using heat pumps, but the latter is applied also during the use of the heat reserved in the environment with high or average temperature. The coefficient of transformation, i.e. the efficiency of the heat pump sharply increases when the temperature drop of two working environments of the heat pump decreases.

It has already been stated that heat pumps can be used as cold sources without any additional capital investments and any changes in the scheme of equipment. The combined use of heat pumps for cold and heat supply purposes reduces the capital cost while increasing the microclimate comfort of buildings.

Cooling by solar energy is studied lesser than heating. The main directions of solar energy use in cooling systems are: establishment of solar domestic refrigerators and solar installations for air conditioning. These installations are periodical and continuously working that is conditioned by the specificity of the use of sun beams of energy.

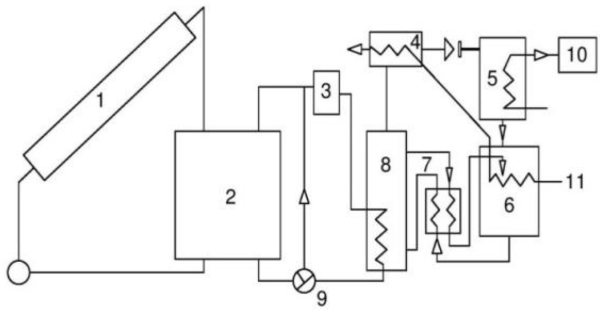
Air conditioning is the most important task of the use of solar cooling, which is based on the work of heat pumps operating on the principle of absorption cooling, steam jet cooling and compressor refrigerators with solar thermoelectric and photoelectric generators. Herewith, a number of economic and technological factors allow to come to a conclusion that absorption cooling devices are more profitable. Regeneration of absorbent is carried out by the heat received from solar heater (picture 11.2). The operation principle of the installation is as follows: hot water from the solar water heater is supplied by circulation pump into the generator where bromine lithium solution is heated and their vapor is absorbed in the absorber where the depleted solution of antifreeze enters from the generator. The work of the installation is provided by the solar heater of "hot box" type having five sections with two-layer glazing of $10m^2$ general square. From the energetic view point, the bromine -lithium absorption refrigerator is very useful, however, its wider use in practice is complicated due to corrosive ability of the working solution and the availability of quite low vacuum in the installation apparatus.

In both the technological and operational viewpoints it will be more advantageous to use the conditioning devices of absorption type. Pentane is used as cooling agent and kerosene is used as absorbent and methane is used as filler. The use of these components allows to realize the cycles in the apparatus under the pressure close to atmosphere that significantly simplifies and reduces the cost of construction of the most refrigeration device. The heating of fluid phase is carried out at the temperature up to 80 ºC in the solar heater of "hot box" type. Consequently, additional fuel heater works with solar heater increasing the temperature of gas forming phase from 80 to 127 ºC. The operating temperature of the evaporator equals to 13 ºC. Full cooling capacity of such installation is 1,5 kW, while each unit of the cold due to fuel consumes approximately one unit of heat. Fuel consumption increases twice in the absence of solar heater.

Another form of the use of solar energy for cooling is the absorption cooling of periodic type. The use of devices working on this principle for air cooling of the dwelling premises is difficult, at the same time, such kind of installations are very perspective for cooling the warehouses of foodstuff, as well as air conditioning of the sports facilities.

During the work of periodic absorption refrigerator emission of the cooling agent from the absorbent happens at the stage of regeneration when the cooling agent is condensed and accumulated and afterwards, is evaporated and absorbed again at the stage of cooling. Thereby, both the absorbent and cooling agent are accumulated separately. Ammonia is usually used as the cooling agent. Sometimes, freon, calcium chloride and other chemicals are used as working substances.

Pic. 11.2 Absorption installation for air conditioning



1. collector; 2. tank – accumulator; 3. doubling energy source; 4. condenser; 5. evaporator; 6. absorber; 7. heat collector; 8. generator; 9. three way valve; 10. cooled room; 11. cooling water

The described installation consists of the generator, condenser, receiver and evaporator [57]. The radiant solar energy heats the blackened surface of the generator oriented under 30º angle to the horizon. Generation process begins when the surface of the generator achieves the external temperature. The extracted vapors of ammonia enter the condenser and after compressing run to the receiver where are accumulated during charging period.

Absorber is cooled down and pressure in the generator falls lower than the pressure of the saturated ammonia vapors in the receiver after the sunset when heating is stopped. Herewith, fluid ammonia from the receiver enters uninterruptedly into the evaporator. After cooling ammonia returns back to the absorber where is absorbed by calcium chloride. The installation is switched to the generation in the morning and continues working for 10hours. Absorption process continues for 14 hours. The cold produced by the device freezes water and the received ice is used for maintaining low temperature within a day.

It is possible to supply the need in cooling within 3 – 8 hours in a day by the solar heat depending on the climate of the territory, constructive features and consequently, the number of similar installations.

The sports complexes include swimming pools very often. These significant water capacities sometimes allow to solve successfully the problem of non-coincidence of the times of solar energy input and maximum need for them. Being the good accumulators of heat energy, water reservoirs together with heat pumps are able to solve the problem of leveling thermal loading and it is possible to accumulate solar energy directly from the collectors in warm weather without using heat pumps that results in energy saving.

Often, there are natural lakes near the sports complexes and they are big capacities of low potential heat energy for heat pumps. Heat exchange of the water accumulator of heat supplied with heat collector of the heat pump can't cause problems in the cases when there is no significant drop in height and consequently, the costs of pumping and pumping facilities. Frequently, artificial lakes and reservoirs are created when there isn't any natural lake and they can play the same role of the heat accumulators for heat pumps.

The solar heating system of the sport center in Shavertown city of Belgium includes artificial lake designed for the purpose of low temperature heat accumulation. Both the direct use of solar collectors' heat when they are in active phase and at high temperature and the use of two heat pumps, one working with artificial lake and other working with solar collector at low temperature are provided in the design.

The necessity of special handling of the ground surface in the sports complexes (establishment of treadmills, athletic fields and playgrounds) can require a great part of expenditures on the establishment of the pipeline network for collection of heat with the purpose of use of low-potential energy of soil and ground waters. The areas available for it can usually be very large.

Summarizing the problems on use of heat pumps for heating and conditioning of sports and other facilities the following should be noticed.

One of the most serious problems of utilization of the Sun's heat energy is the mismatch in the peak time of thermal load on the solar heat supply station and solar radiation intensity. Heat pump systems of heating and conditioning are deprived of this problem and transform low potential solar energy accumulated in the soil or ground waters of the upper layers of soil into the high potential heat energy which can be directly used for heat supply.

Factually, ground is a thermal accumulator of unlimited capacity accumulating solar heat. Geothermal heat generated in some regions can also be easily used by heat pumping installations. Natural or artificial water reservoirs having the best heat collection conditions are more convenient. Thermal pump systems of heating can be used for cooling and conditioning without any capital investments or alterations.

Comparative high price, necessary exploitation and repair costs and the need for additional energy sources compared to solar energy systems are the shortages of the heat pump systems.

The expediency of the use of heat and cold supply system using heat from ground or water bodies is determined in every concrete case based on the local climatic conditions, heat engineering features of soil, availability of other energy sources, fuel prices and so on. Generally, it can be considered that the use of heat of the upper layers of soil for heating and cooling purposes will allow to reduce the cost of heating and conditioning by 50 – 60%.

12. MANAGEMENT OF MICROCLIMATE

12.1. Complex structures

The building complexes are equipped with special installations for heating, cooling and lighting to provide their normative microclimate. As a rule, each installation has the automation system allowing to manage it. At the same time, the complex of installations creates interconnected single power economy. For example, in a sport complex the electricity needed for additional lighting of the tribunes of large capacity in a short period after the end of match can be obtained by turning off a part of air conditioning installations. This energy can be obtained also by turning off the refrigerating machines used for freezing ice of the artificial sports rink. Analogical task occurs while applying installations which use the heat of solar radiation or the heat of the upper layer of soil, as well as the accumulation installations.

Thus, there is a technological process-formation of the internal microclimate which is determined by space-planning and design solutions of buildings, indicators of outdoor climate, performance characteristics of the object and power plants.

Automated management systems have long been used for the management of various technological processes and the buildings energy system including the indoor microclimate facilities. Building energy management systems (B EMSs) are essential components of modern buildings. They include control heating, ventilation, and air conditioning (HVAC) and lighting systems in buildings; more specifically, they control HVAC's primary components such as air handling units (AHUs), refrigerators, and heating elements. In the United States, about 40% of total energy consumption and 70% of electricity consumption are spent on buildings every year. These numbers are comparable to global statistics that about 30% of total energy consumption and 60% of electricity consumption are spent on buildings [58]. Automated management systems (AMS) promote the solution of the issues related optimal energy efficiency, energy security and comfort condition in buildings.

An automated management system of technological processes (AMS TP) is the man-machine system providing automated collection and processing of the information necessary for the management optimization. The automation process presupposes the selection of such kind of management version through which maximum or minimum values of some criteria characterizing the management quality are achieved. The expediency of AMS TP development is determined by the economical calculation where the reduced cost of system development and exploitation are the target functions [59]. It is also possible to solve the problem of optimization of the technological scheme of AMS, types and forms of the equipment, from which it composed by minimizing the value of the reduced cost. The main task of AMS development is the minimization of the operational and energy expenditures intended for the provision of technological process (picture 12.1). For example, the use of a flowchart (picture 12.2) to regulate the work of the engineering facilities of the Sport Palace in Baku city allows to approach the solution of energy saving problem from complex scientifically proven positions by optimization of the work regime of technological equipment.

The automated system works on the basis of a mathematical model allowing to save the preset parameters in the premises not depending on the meteo rological conditions and their changes due to automatic selection of optimal work regime of the equipment. The computerized system calculates heat energy consumption periodically and regulates the work of engineering facilities of the complex.

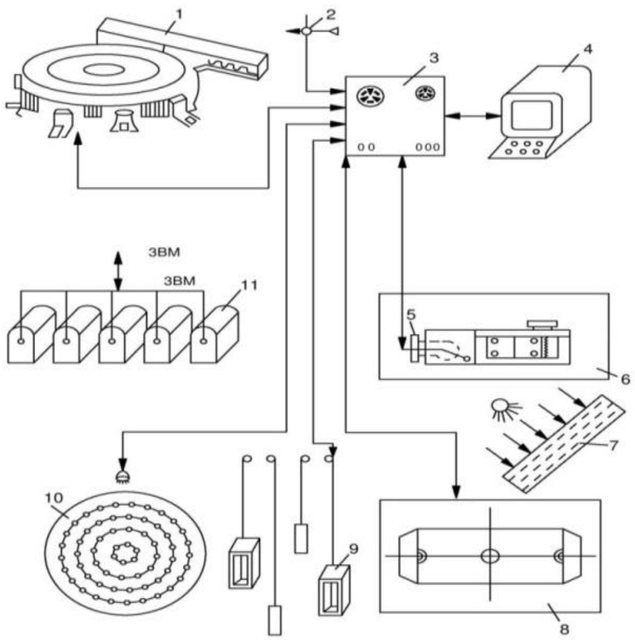
It is necessary to state that the optimization system regulates different temperature levels in the premises being supplied by the central conditioning system. The suggested diagram of linkage of the optimization system allows to maintain necessary parameters in all premises and sport halls that leads to additional energy saving and establishing necessary microclimate in each part of the building.

We will show how the economical and technological effect is achieved in the example of HVAC system regulation.

Temperature sensors 3 providing the information about indoor temperature to the devices regulating temperature 5 in the central control cabinet and module of twin distribution 4 are put in the supply and exhaust systems. Temperature regulator receives signal from the sensor installed outside the building and after comparing the temperatures gives command to the executer mechanism 7-two-way valve with electric drive and 8-three way valve with electric drive. Depending on the difference between the outside and inside temperatures, regulator 5 gives command to the three-way valve 8 and two way valve through twin module 4 which supply the preset amounts of hot and cold water to establish the required temperature. Thus, the temperature is regulated by two-way and three-way valves (picture 12.3). Completely close position of the valve supplying cold water corresponds to completely open valve working in the regime of hot water supply and vice versa.

When the temperature of the outside air is lower than the critical value, signal comes from the temperature sensor 6. Shutter with electric drive 2 instantly close the access of cold outside air to the conditioner and ventilator 1 that extracts cold weather from the premises is activated. Three way valve is completely closed, accordingly two-way valve opens the access to hot water that prevents freezing of air heater. Afterwards, two – way valve is gradually closed and accordingly, three way valve opens access to cold water until the preset temperature is not obtained in the premises. The described automated system of regulation excludes sharp loadings through uninterrupted selection of optimal work regime of conditioner and saves energy resources.

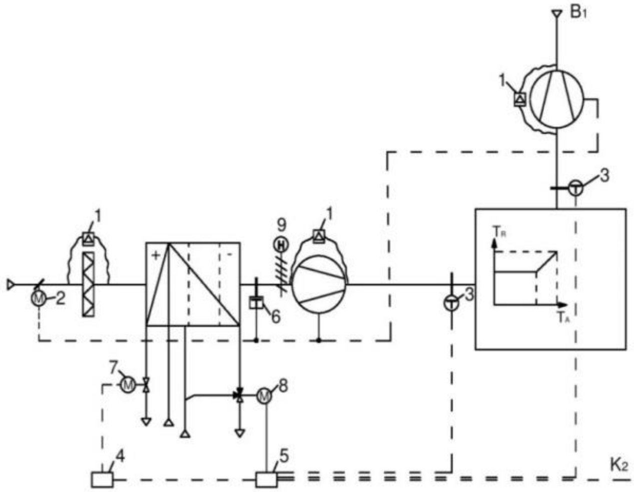
Pic. 12.1 Functional flowchart of the system of optimization, regulation and control of the engineering equipment of the Sport Palace in Baku city



1.the building of the Sport Palace; 2. meteostation; 3. computer; 4. display; 5. regulating valves; 6. conditioner; 7. solar water heater; 8. ice floe; 9. elevator; 10. lighting system; 11. refrigerating station

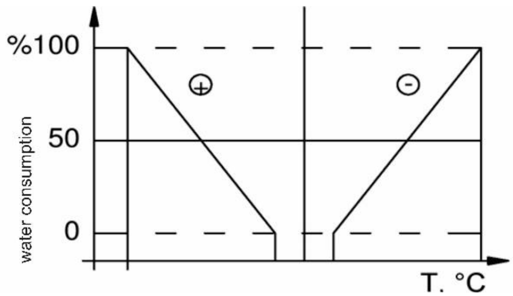
The automated management system is based on the use of regulators allowing people to interfere operatively in the management process. The use of computers significantly increases the efficiency of the management system, as for the first, its work is based on constant modeling of really happened process, secondly, they choose the most optimal management version, thirdly they work on previously developed multipurpose program.

Pic. 12.2 Functional flowchart of conditioning



1.device for measuring pressure; 2. shutter with electric drive; 3. temperature sensor; 4. twin module; 5. temperature regulator; 6. temperature sensor protecting against freezing; 7. two way valve with electric drive; 8.three way valve with electric drive; 9. manual shutter

Pic. 12.3. A scheme of work of temperature regulator



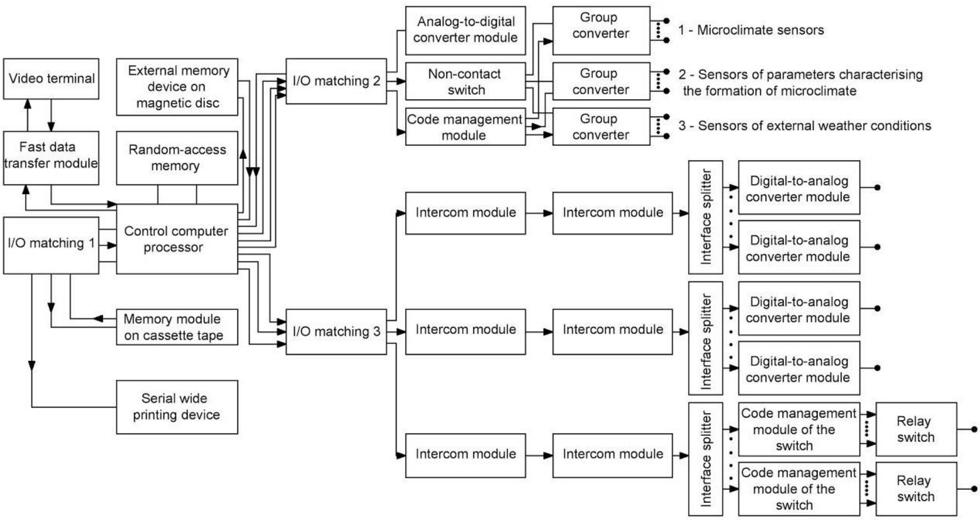
The schema of automated microclimate management system of the sports complex is given in picture 12.4. The automated management system functionally consists of three interconnected parts:

1) *Measuring – identification part realizing the reading of analogical values, limit values signaling elements and the indicators of the executive organs' position, and the devices transforming into the digital form;*
2) *The central part of collection and processing of the measured data and giving a command to the executive mechanisms of regulation including switchboard, communication line, computer and control panel.*
3) *Executive part realizing the management of regulation by the mechanisms of technological equipment through special devices.*

Two main information flows can be distinguished in the computer system of connection with control object: the flow of the measuring information entered to the computer from the sensors of physical parameters of the process (temperature, pressure, liquid consumption, illumination and so on) which characterize the position of the control object and the flow of the managing (command) information passed from computer to the entrance of executive devices of the control object. Usually, the scope of the measuring information about the state of the control object is significantly more than the scope of the managing information received from computer as a result of calculation according to the management algorithms. The structure and character of the system of connection of computer with the control object is significantly dependant on its form.

Information exchange between specific devices of the computerized system is implemented through interfaces I and II. Information exchange between the main (operative) memory, processor and input-output channel happens through interface I. All communication devices of computer with the control object are connected to interface II. The receipt of information in computer from the sensors and passing the data from computer to the executive devices is implemented through the input – output channel.

Pic. 12.4 Scheme of the automated microclimate management system of a sports complex



1, 2, 3 and 4 devices for providing the data to: the intermediate carriers; the documental fixation; the visual checking of information and the environment, respectively.

A block of external interruption of processor according to the signals coming from the sensors of the control object, the device of running time (electronic clock-timer) forms signals for the organization of different cycles of information processing and management of the object.

Information of the control object is received from the sensors with continuously changing analogical signals and from widely used two positional discrete sensors at the exits of which signal has only two values: "yes" and "no". The sensors with digital information have been widely used due to their sim plicity and exactness of digital signals transmitting as well as convenient use of these signals in computer.

The flow of the measuring information is organized through the means for transmitting signals from the analogical sensors and from two-positional or digital sensors. The first group of means include switchboard of analogical signals (SAS) and analogical digital transmitters (ADT), the second group includes switchboard of digital signals (SDS) and the device for accepting of digital information (DADI). Switchboards of analogical and digital signals together form inlet (collecting) switchboard implementing separate on time connection of one of numerous sensors to the inlet of information receiver.

Regulators, registers and self-recorders and other devices and knots of local automatic systems are assembled in the local control panels installed in a direct proximity of technological objects (conditioners, illumination systems, refrigerating stations and so on). The local control panels are not constant work place of personnel. Inspectors and shift foremen use them as required.

Computer complex of the automated management system is located in the central control station. It consists of the followings:

- *Devices of information subsystem (switchboards of signals from the sensors, analogical-digital transformers, instruments for disconnection of parameters, and for inquiry about the condition of two- positional sensors);*
- *Devices of the managing subsystem (arithmetic and memory device, device of multiplex connection and so on);*
- *Panel of the programmer – operator;*
- *Display and printer with a device for program input and data output.*

The level of reliability, consciousness and microclimate management efficiency of large sports complexes is associated to a considerable degree with the amount of the information received by the operator for analysis and in many cases for following researches. The device taking out information from computer can be conditionally divided into following groups: device for putting the data to the display screen, panel and indicators of different type, etc. for visual checking; device documentally fixing the issued information in the form of text, graphs and pictures; device for providing the data to the intermediate carrier in coded form (paper tapes, punch cards and etc.), device for providing the data to the external environment (digital transformers, connection lines and etc.)

The system is functioning in the following form: the information entering to the memory device of computer through substation and condenser perio dically from the measuring sensors located in different parts of the building is processed by special programs and compared with the regime required for the given moment. In case of deviation from this regime, necessary signals are worked out and given to the executive mechanisms and regulating organs through the condenser and substation are worked out. At any time, the serving personnel can receive the data about any point of the object on the screen of control panel and interfere the systems operation, if necessary. The system immediately informs about the accidents and diagnoses this fail. Since the data derived from measurements and calculations are collected in computer, they can be printed any moment. It is possible to analyze the work and the efficiency of the equipment used, energy consumption and energy saving. Herewith, the data for any stretch of time can be given according to both the group of selected points and all points. The data on the quantity of saved energy, electricity and thermal energy consumption, optimal start and stop times of the equipment and the climatic data about outside air and solar radiation are especially interesting.

Two approaches are used during development of the automated micro climate management system of building: thermo-dynamical, when physical processes of heat and mass exchange happened in the building are studied, and cybernetic, when the building is considered as “black box” and intercon nection of input and output values is studied. It should be noted that the first approach called as systematical allows to consider the system “heating installation-object” as interconnected non-linear with variable structure. The solution of the problems in thermodynamic approach is based on reliable mathematical models of the regulation system elements. Automated microclimate management system of large sports complexes can be designed both for re-edified and reconstructed objects.

The main tasks of the automated microclimate management system of sports facilities are the following:

1. *Significant increase of the performance level of the sports facilities by con ducting high quality measurements of regulated parameters, instant reve aling of faults and optimization of their elimination ways, rational use of personnel;*
2. *Security of the most important equipment of the building;*
3. *Reduction of the maintenance cost due to the optimization of energy con sumption for providing the microclimate according to world standards taking into account technological features of the exploitation of the sports facilities, documentation and analysis of statistic data on energy consumption; con sideration of work time of the energy consuming equipment and establish-ment of priorities and repair date, reducing the serving personnel.*

Efficiency and reliability of the automated management system of depends on how successfully will be solved the following issues:

- *Determination of main management task and optimization criteria;*
- *Development of the management algorithm, i.e. determination of the sequence operations from measurement to managing effects in one isolated (closed) management cycle and determination of the scope of the measuring and managing information;*
- *Revealing of actual features of the energy facilities (building and ice rink, etc.) by special experiments and zones of sensors installation for proper characterization of the object;*
- *Development of mathematical description of the energy facilities and met-hods of mathematical modeling for achieving the preset regime;*
- *Choice of computer, mathematical securing and main principles during development of software;*
- *Choice of devices for communication with controlling object;*
- *Development of software of the system.*

12.2. Peculiarities of the automated microclimate management system designing

When designing the system, it is necessary to proceed from general requirements of the automated management systems of technological pro-cesses to: the exactness and implementation speed of operations of input of measuring information from the control object; the structure of communication devices of the control computer with the managing object; the parameters of the apparatus intended for normalization, commutation, transmission and transformation of signals; the methods of dealing with interference as well as the algorithms and programs of the information transmitting and transformation procedures.

The most expedient method of the sports facilities' microclimate control is a management structure under which separate parameters of microclimate are regulated by corresponding automatic regulators, and the control computer processing the measuring information calculates and optimizes the setting of these regulators. Such management structure increases the reliability of the system as a whole, as its operability is maintained even when control calculator refuses. Besides, the control computer in this structure can be simpler that reduces the requirements on its quick performance and other characteristics, and there is a possibility of the practical realization of more effective algorithms of the optimization processes requiring large scope of calculations.

The followings are measurable non-regulated parameters: temperature and humidity of the outdoor air,wind speed and direction, atmospheric pressure, solar radiation, temperature and pressure of water in the supply pipeline of the thermal network, temperature and pressure of vapor in the thermal network and the temperature of cold water supplied to irrigation chambers and surface air coolers of the air conditioning system.

The followings are the measurable output parameters characterizing microclimate: air temperature, relative air humidity and air motion speed in the working zones.

The followings are measurable output parameters according to which it is possible to determine the management efficiency of:temperature and pressure of water in the return pipelines, temperature and pressure of vapor in the return pipelines, the consumption of heating water, cold water and vapor, and elec tricity consumption.

The followings are regulated parameters which can be changed by corresponding executive mechanisms: temperature of incoming air, temperature of hot water after mixing pumps and the amount of incoming air.

It is expedient to consider automatic defense of equipment and blocking in order to increase the work reliability of installations forming the thermal regime of industrial buildings.

It is recommended to use blocking device to supply minimum amount of outdoor air in cold season of a year and for air conditioning system in hot season of a year in air conditioning and incoming ventilation system working with variable amount of external and recirculation air.

Electric motors of the fans of air or air-heat curtain should be locked with the mechanism of opening of gates and the doors of technological openings served by curtains. Moreover, it is necessary to disconnect the fan of air- heat curtain and to reduce the heat carrier supply of calorifiers to a minimum after closing the gates, doors and technological openings, but not earlier than restoration of rated air temperature in the premises.

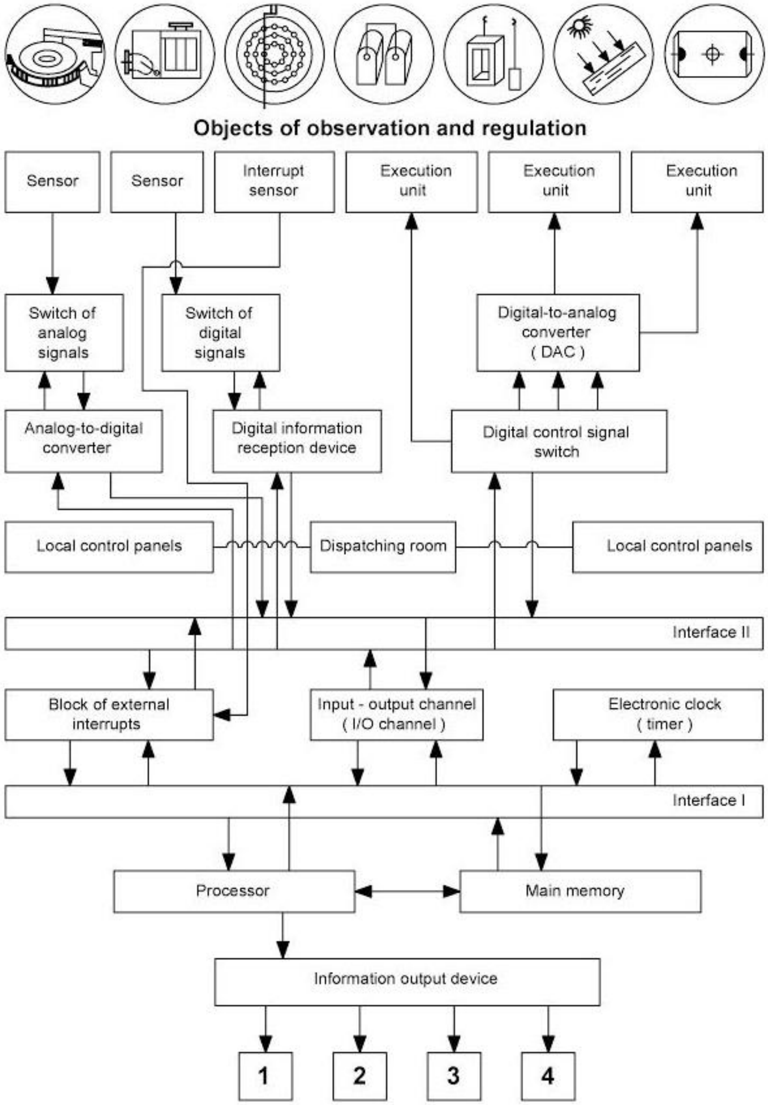
It is necessary to use structural information scheme determining a complex of control objects, sensors, control and calculation devices and other aggregates of the control computer as well as executing and regulating devices and the devices establishing the necessary informative connection between them while determining which measuring, managing and signaling information is circulated between different devices of the system.

The structure of the complex of technical means of the automated management system is presented in picture 12.5 consists of computer and device of communication with the object (DCO).

It is necessary to use serially issued apparatus and the possibility of passage to more perfect calculation technology without substantial alterations while selecting the calculation technique. It is also obvious that, energy management of the large sports complex can't be entrusted, for example, to the computer center due to the necessity of the work of the system in real time scale and regimes of uninterrupted management. The calculating complex must consist of managing computers working in real time and having ramified system of both the input and output devices for connection with the control object. It is not necessary to make great demands on quick performance of the computer complex because of slow variation of the heat process in the building. Moreover, this complex should be complete with respect to computer software, i.e. it should contain operation system with working ability under real time regime of implementation of tasks while maintaining a dialog mode of use and should have a full translator of with high level language, library of main programs and program library for working in real time scale including input-output program and processing of analogical and discrete information, possibility of edition, arranging, segmentation and work with the files on discs. Besides, relative small sizes of computer complexes, autonomy, possibility of further development, relatively lower price and small number of maintenance personnel were the additional requirements.

Matcher of input-output (IO) are used for connecting DCO to the interface. Three IO matchers can be connected to the processor. One of them is used for connection of the device to the magnetic tape and wide stamp. Two others are used in the following manner: one for input device, other for output device. Matcher IO can be replaced by RIM interface.

Pic. 12.5 Structure of the complex of technical means of the automated management system



DCO is divided into two groups according to its appointment. The first group implements input of the measuring information to computer. Input device consists of the module of analogical digital transformer (MADT), con tactless switchboard (CS), module of coded management (MCM) and four groups of transformers (concentrates). The second group consists of output of the processed information from computer to the executer regulation mechanisms, for example, heating and ventilation.

The output device consists of the switchboards which issue exit to necessary address and digital-analogical transformer implementing the transformation of digital signals from computer and electric signals of constant currency. These signals enter to the managing organs of the executive mechanisms. Analogical signals formed from binary code of the managing signal accept one of many possible values according to the value of the digital signal, i.e. according to its binary code. The splitters of the RIM interface play the role of the switchboard. They are connected to the interface by the modules of internal system communication (ISC) and occupy two places in every interface.

As it was mentioned above, additional equipment is used for the connection of DCO to the computer complex. This equipment is placed in additional stan dard box in direct proximity of computer. Two matchers of input-output (IO), module of analogical digital transformer (MADT), contactless switchboard (CS), module of coded management (MCM) and module of internal system communication (ISC) are located in this equipment. The task of DCO includes the provision of operative information exchange between computer and gras sroots devices such as sensors of the first size and executive devices of heating and ventilation. These devices implement collection, transmitting and transformation of measuring information entered to computer as well as their supply from computer and transformation into managing signals. The main function of DCO consists of implementation of input-output of analogical and discrete signals of exchange. Order and speed of information exchange with grassroots devices, as well as processing of the information is completely determined by computer software. The special systematical software called "drivers" which consist of a set of special commands is used to exchange of information with DCO. These drivers are included in the operating system and are used together with it.

Transformer of the measuring group GT is intended for proportional transformation of signals in unified normalized signal of constant tension.

MADT is intended for proportional transformation of analogical signal into binary code and gives results for direct entrance to the calculating device through the interface. Acceptance of the analogical signals can happen either from the switchboard, or directly from the sensors. Input signal must be at the range from -5 to +5W, input resistance -1m Om, the time of one transformation is 30 mks and the transformation error is 0,1 %. The device is mounted in the standard line. MCM is intended for management of group transformers. It implements receiving and storing of digital binary codes entered from the computer complex and management of the switchboard of electric chains of continuous current of a remote group transformer. Module has galvanic disconnection of output keys from the management chain.

Measuring sensors, as well as indicators of the limiting values of the internal microclimate parameters and position of the actuators are determined in different parts of the building and are attached to the substation by cables. Cables from the controlling organs of the actuators of electric drives regulation are connected to it for dampers, valves and pumps. These substations are located near the measuring and regulating objects in order to reduce both the length of wires and the influence of hindrances on the measuring chains. There are special devices in substations for transmitting signals to standard (normalized) form and primary commutation. There are four such kind of substations and their number is determined according to the number of measuring devices. The substations with multichannel connection lines are connected to the concentrator determined in the dispatcher. Concentrator contains following devices: measuring, transforming of analogue-figure and vice versa and connectors through the switchboard to the measuring and controlling point. The data is transmitted from the substation to the concentrator and vice versa by analog signals and from the concentrator to computer and vice versa by discrete signals. Mini computers, operator control panel with video-terminal and printers are also placed in the control room.

The system works in the following manner. The management process is subdivided into cycles of equal duration. Serial interrogation of sensors is implemented at the beginning of every cycle. The binary code of interrogating sensor passes through the matcher IO 2 to the contactless switchboard and comes to MCM. Managing signal is given to one of the group transformers from MCM. Analogical signal from the interrogating sensor enters to the module of analogical – digital transformer through the group transformer and contactless switchboard where it is transformed into binary code and enters to the processor through matcher IO. The time spent for transformation and input of the measuring information to the memory device is much less than of the fluctuation period in the managed process. Therefore, all measuring information of one cycle is entered to the memory almost simultaneously. After that all measuring information is delivered to the memory device, the processor processes the entered information within some time and counts the necessary managing signals, then the binary code of each managing signal goes to the module of digital analogical transformer passing through the matcher IO 3, the modules of intersystem communication and the splitters of interfaces, where is transformed into the analogical signal or through MCM of contacts comes to the relay switchboard. In the actuator, analogical managing signal produces the value of managing influences which is stored unchanged over the period of the current management cycle.

Processed and generalized information about the course of the process and the condition of the technological equipment is transmitted by processor through the matcher IO to both the external memory module in the cartridge magnetic tape and the sequential wide print device, and also to video- terminal through the fast transfer module. After that the system goes into standby state or performs auxiliary calculations which can be interrupted (without disturbing the program and intermediate results) at the time of the next control cycle.

The heat processes in the building as a whole change slowly, therefore, a synchronous principle of the computing system communication with the object in real time scale is chosen. The management process is divided into cycles within 10-15 minutes. The computing system is always in the standby regime. The cycle start signal enters from electronic clocks of the controlling computer to the interrupting device. Management process starts. Measurement sensors survey occurs at the beginning of every cycle. This information enters to the storage (memory) device through substations, concentrator and the transformer into the digital form. The time spent on the transformation and input of measuring information to the computer is significantly less than fluc tuation period in the controlled process. Therefore, it is considered that measuring information is introduced simultaneously. The received information is processed in computer using special programs modeling the thermal behavior of the building, its preset thermal conditions and optimizing the required heat input from the heating and ventilation system for maintaining this regime. Signals are produced when the change of the regime preset in the previous cycle is necessary. These signals enter the managing organs of the executive regulation mechanisms through the concentrator, substations and transformers.

The operating personnel may receive data about any point of object and the work of the system as a whole at any time and intrude into their work. For this there is a second circuit of the system interrupting the above mentioned closed process upon the operator’s command. In this case, the operator takes management upon himself, but its action is controlled by the system. If the action of the operator leads to the occurrence of accidents, for example, possible freezing of the heating system, then the system warns the operator about it. The system also slowly informs about any emergency situations (for example about broken windows, faulty calorifier, pressure drop in the pipeline and so on). The data derived from measurement and calculations are collected in the computer database and can be printed any time. Based on this database it is possible to analyze the work of heating and ventilation systems, the effi ciency of the used equipment as well as the energy and heat consumption and energy saving, etc. Herewith, the data for any period of time and both about the group of the selected points and all pointes can be provided. The data on the amount of the saved energy, electricity and heat energy consump tion, and optimal start-stop times of heating and ventilation equipment as well as climatic data are especially interesting.

The program structure includes the principles of stepwise commissioning and maintaining the system's work capacity in case of failure of individual sections. At the first stage of commissioning the system operates on open-loop control scheme where only the first two parts of it are realized and the system works in the monitor (advisor) regime. In this case, measuring information entered from the control object is processed in computer and optimi zation is implemented according to special programs and the recommendations on which control effects on the heating and ventilation mechanisms should be performed for achieving preset regime are given. Following these recommendations, the maintenance personnel fulfill some or other actions.

The software consists of the disc operation systems including both the possibility of working in real time and the works in dialog regime. In addition, possible translation from Fortran and Assembler as well as editing, grouping and program debugging tool and the available specialized program packages are used. The possibilities related with the time service, i.e. waiting for preset time for launching the processing operations and managing the work of the devices of communication with the object are used. As the capacity of the operative memory is not enough for simultaneous location of all programs, the possibility of work with files for accumulation of necessary information is used as well.

The software system is divided into three program groups according to destination: optimizing, main operating and auxiliary for serving the system.

The basic approach to the system programming should be developed during the creation of the software package. This approach is determined by the aspiration of having a machine independent system so that not to have the necessity for complete reprogramming while passing to other types of computing devices. All computer software translates into the algorithmic language of Fortran in the form of separate subprograms. Those programs which are difficult to realize in Fortran, for example, the programs managing the devices of communication with the object is written down in Assembler using macro-means of the operation system. The necessary macro-commands and drivers of the devices of communication with the object include operation system during its generation. The large programs should be segmented in Fortran in order to keep within a predetermined capacity of operative memory (RAM). The programs must use an external memory on discs for the accumu lation of the time data about the condition of the process. The results of work of each management cycle are necessarily recorded on the magnetic discs. Programs are developed in such a manner that they could be continued after switching of the disc to another computer in case of failure of computer. The most important information obtained within a day is recorded on the magnetic disc for long - term storage.

12.3. The software of the automated management system

The software of the system contains the operating system of computers allowing to work both in real time and in interactive mode and the system of software package. The possibility of program translation, editing, grouping and adjustment shall be provided. The operating system includes the means associated with the time service, i.e. waiting for the preset time to start the process and management of the work of the communication devices of with the object, as well as the possibility of work with the files saved in the external computer.

The major part of the software package is written in Fortran language. It is expedient to write the program on the management of communication devices with the object in Assembler using macro-means and drivers. Software package is written in the form of individual interconnected subprograms. Herewith, the possibility of continuing the work in other computer by means of rearrangement of magnetic carrier of the failed computer is envisaged. The software package is intended for the control of the operation of the entire system. It is divided into three groups according to destination: optimizing programs, the main operation programs and also auxiliary programs for serving the system.

The programs for calculation and optimization of heat consumption for heating implement two main functions: the heat consumption required for maintaining of the preset microclimate in the separate parts of the building is periodically calculated, and the numbers of the heating devices and heat carriers are determined. The regime of reducing temperature to the permissible minimum level in non-working hours and returning to preset regime is also determined.

The software system controlling the energy consumed for providing technological conditions of operation of sports facilities includes the following programs: remote switching on and off of energy equipment; determination of the time of supply of the required amount of energy depending on the parameters of outside climate and technological conditions of operation of facilities; restriction of peak energy consumption through permanent discon nection of subsidiary consumers, if the total load exceeds the allowed power; selection of an optimal combination of temperature and humidity of the out door air for air conditioning system depending on normalized indicators of the indoor microclimate and recirculation level; control over the indicators of the indoor climate in different parts of the facility, management of illumination of the sports facilities depending on operating conditions.

The main working programs consist of the following subprograms: "dispatcher" (organizing all process of the system functioning); collection of primary measuring information and estimation of its reasonability; basic processing of measuring information; documentation of management process including the reports on the system condition; control over the heat regime parameters including programs of regimes; time services (providing call of required sub programs when due time comes); watching the development of process; control over good repair of the system functioning; calculation of factual energy consumption; inclusion of warning and emergency signalization.

The "dispatcher" subprogram manages all the system's operation. In non-working condition it is in the regime of waiting the time service signal of computer. The program is activated and begins to implement the required succession of the calls of the corresponding subprograms when due time comes, for example every 10-15 minutes of real time. The "dispatcher" is in wait regime again upon completion of one cycle of process from the beginning of measurements to the delivery of managing signals to the executive mechanisms. Moreover, the program can be activated in other moments of time upon the entrance of the signal about emergency situation for diagnosis of reasons. At the beginning of activation, the "dispatcher" program checks good condition and gives corresponding diagnosis to the operator. It is entrusted with the function of completion of the process cycle while implementing ne cessary actions for the process repetition including the possibility of continuation in other computer.

Subprograms intended for the collection of primary measuring information provide interrogation of the sensors of measurement, compensation and their linearization in case of necessity and also reasonability checking. The reasonability means the data either sharply declining from other data according to their values or inadmissibly sharply changed in comparison with previous cycle. In this case, the data is recalculated (up to three times). In case if positive result not obtained, the operator is informed about it to make proper decision. The system is waiting for response nearly for 2 minute, after it ignores these data and continues working.

Subprograms of basic processing of measuring information serve for recalculation of the data of sensors in physical values and also systematization, filtering and accumulation of the obtained information. Wherein, the tabular values with linear interpolation are used.

Subprograms of the management process documentation record all processes and the actions of operator in paper. They realize static estimation of the data on measurement and calculation, condition of the heating and ven tilation equipment, prepare the daily, weekly and monthly reports on average, minimum and maximum values,about emergency situations, energy consumption, appraisal economy, condition of equipment and the commands of the operator. The results of processing are passed to subprograms for printing.

Subprograms on control over the parameters are implemented together with optimization programs and are intended for making commands on the management of heating – ventilation equipment. They store the data about the processes happened in the system during weekends and other days, as well as about heating and ventilating devices and their controllability. Subprograms must be implemented in the following manner: the regime preset at certain time is compared with factual regime. In case of declination of factual regime from preset regime, a command is given to corresponding management device. The data of the regimes can be changed by the operator panel.

Subprograms of time service distribute start-up time of different devices for regulation of peak energy consumption. For this purpose, the time service should allow to establish the preset interval of time and react to its completion, to calculate the current time of days, calendar date and determine the days of a week and have relevant regime schedule. It is supposed that the exactness of the time service control of time intervals, current time and date depends on correct establishment of date and time by the operator, who loads the system.

Subprograms watching the process development within long time interval issue the data necessary for controlling and estimation of the system's behavior. Subprograms choose separate values on the instruction of the operator determining the type of work and time intervals within which the process shall be watched. The corresponding table is printed at the end of the process.

Subprograms of control on good condition of the system functioning represent a number of subprograms imitating the work process of the system with preset parameters and results. They are activated within time intervals when the system is in waiting state and on special inquiry of the operator. The works of main subprograms of the system are checked through obtaining standard input data and comparison of the obtained results with previously known results. In case if declinations of subprograms are revealed, the degree of seriousness of errors is determined, diagnosis is made and the data is given to the operator. In addition, they check the correctness of information transfer between separate devices using imitators of signals.

Subprograms of calculation of factual energy consumption calculate total energy consumption in the building and accumulate the data in the form of tables indicating the change of consumption on time (during the day, week, month and year) getting them from programs of heat energy optimization. These subprograms also accumulate the data about average daily outside and inside air temperatures.

Subprograms on warning and alarm signaling register and diagnose different emergency situations during operation of heating and ventilating systems. Two types of situations are differed: really emergency, for example temperature fall in the main pipeline or the danger of freezing of different elements of the system and the situation approaching the emergency situation, for example temperature fall due to the broken windows, failure of separate elements of the heating and ventilation systems under which the working ability of the heating system is wholly maintained. Alarm subprograms react to the first type of situations immediately (not later than 10 seconds after the event), when receive signals on the break. Subprograms reveal the second type of situations after processing the measurement results and determining exceeding of the measuring parameters the limit values. Information about this type of situation should enter within one minute after revealing.

Auxiliary service programs of the systems contain following subprograms: connection of the operator with the system; location and relocation of infor mation from external memory of the computer; output; exchange of information with separate devices connecting the system with the object.

The program of connection of the operator with the system should consist of several subprograms. Their main feature is the possibility of implementation at any random time according to the requirement and instruction of the operator. As the characters of input of these requirements for execution of the command of the operator are different and the time intervals between the implemented operations can be mutually covered, the working time of com puter on these operations should be divided. This division is realized by special managing program using the mechanism of programmatic and external stay of the computer taking into account the operations priority and possibility of interruption up to the end of the process.The programs must contain a program, checking the information introduced by the operator for consistency of his actions when giving instructions to the system and protection against faulty actions.

Simplified language of symbols and understandings has been elaborated for connection of people with machines. Commands are collected on the screen of display terminal in strict succession using this language: at the beginning principal data, then auxiliary and at the end, more detailed data. Date (day, month, year), time (hour, minute), decoding of the symbolic signs of commands, auxiliary function and detailed data are highlighted in the display terminals during responses. The text of response confirming the implementation of command is given below.

Work in the regime of dialog with machine using terminal devices allows to interfere in the work of the automated system using simple, preliminarily programmed commands of the program. The operator can require and reproduce the data, commands and different situations on the screen and analyze the accumulated information. Alarm signals are highlighted at non-occupied part of the display screen, as well as cause lighting of the alarm indicator or sound signal activation. Besides the alarm indication of the type of fire, pressure fall, the lack of energy, failure and so on, information about the date and time, the place of danger and the recommended measures on its liquidation are displayed. Also, drawings and schemes of individual parts of the system can be displayed indicating dangerous places.

Subprograms of placement and movement of data in the external memory of the computer implement the work with files. Files are the organized collection of the data, saved in the external memory of the computer. Subprograms realize data record, search and alteration. Physical representation of the data depends on the memory device in which they are stored, but in any case, they are presented in the form of fixed length blocks. Operative data, for example for current days or weeks shall be placed in high-speed devices, for example, on magnetic discs and data gathered for a day or a week shall be directed to slower acting device, for example to magnetic tape for long term saving. Herewith, the disc will be released for the next portion of operative data. These programs shall provide storage of files, i.e. possibility of their restoration after being damaged as a result of equipment failure.

Subprogram of output is used to organize the information terminal display on screen for maintaining staff. These programs realize printing various tables of reports on paper tapes.

Subprograms realizing information exchange between individual communication devices of system with the object must be developed using macro facilities of the operation system and drivers. All features of exchange with computers and response to different situations on the preparedness or refusal of the equipment, as well as validity of the transferred information must be reflected on these subprograms. In addition, these programs must contain protection against incorrect actions of the operator as a result of which the heating and ventilation devices can fail.

12.4. Mathematical model of microclimate formation

Mathematical model of microclimate formation includes a complex of mathematical methods, models and algorithms used for the functioning of automated management system. Mathematical formulation of the management task consists of two elements: mathematical model of the object and management criteria.

It is expedient to use systems approach method during development of the mathematical model of microclimate formation of sports facilities. In this case, the system is an energy economy of sports facilities including the building of the Sport Palace, artificial ice floe, devices for air conditioning and cooling of the ice floe, heliosystems and illumination installations, etc. The energy economy system of sports facilities is characterized by complex linkages. Its individual elements represent a connection, which give the whole system new qualities that are absent in each individual element. For example, load on conditioners in the system "Sport Palace-conditioning installations" increases with increasing the outside air temperature, but it decreases in the system "Sport Palace – air conditioning installations – helio devices operating for cooling".

The main purpose of the systems approach to the management tasks is the revelation of real functioning mechanism of the considered system and improvement of their adaptation to the external conditions change, i.e. determination of minimum energy consumption for sports facilities functioning in the case considered by us depending on the technological features of their exploitation and the change of climatic impacts. As a rule, the researched system represents the elements of higher order system. Indeed, the system "energy economy of sports facilities" is the element of the energy economy system of the region.

Energy economy of sports facilities (picture 12.6) is associated with direct external connections with energy economy of the city and the energy potentials of the solar radiation, wind, upper layer of soil and air*. Except external infor mation links, availability of internal direct and feedback linkages is characteristic for energy economy of sports complexes. Initial internal information includes systematized analytic, tabular or algorithmic description of appropriateness and characteristics of technological processes flow (indicators of internal climate depending on the types of occupation in the Sport Palace, the temperature of the ice surface, switching on and off of the lighting system and information panels, etc) characteristics of the construction and heat engineering indicators of the power system elements.

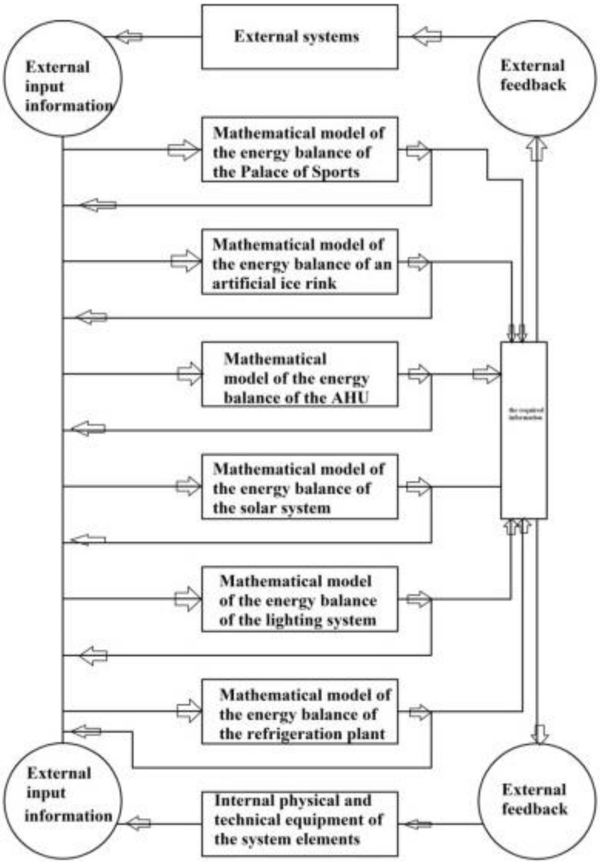
Similar to the indicators of external links, each indicator of the internal links influences the energetic level of installations. So, the change of the technological process indicators in the premises of Sport Palace affects not only its power balance, but at the same time the energy consumption value of air conditioning installations changes leading to the change of energy consumption of heliosystems.

* *In cases if there are installations using the wind energy, the heat of upper layers of soil and heat content of the outdoor air.*

The exceptional complexity of the technological structure of the sports complexes energy economy and the system of interconnections between individual power objects predetermines the expediency of its division into a number of systems. The integrated energy system of the sports complex standing on the upper hierarchic level may be divided into five main specialized systems including: the Sport Palace as a whole, artificial ice floe, installations on heat and cold supply, lighting installations and power consuming technological equipment. Each of five systems has mathematical model of energetic balance.

Interconnection of input and output information on both all technological tasks and all temporary stages shall be realized in the system of the energy economy management of the sports complex. Initially accepted structure of the model will inevitably be undergone to different change types. Its impro vement is possible after accurate definition of parameters of the model on the results of comparison of output data received during modeling and in – situ experiment. Thereby, requirement on provision of accuracy of modeling leads to the necessity of some changes determining the succession while designing the model and completing it with special calibration stage.

Pic. 12.6 System of mathematical models of energy management of the sports complex



Taking into account the considerations stated above, the task on mathematical models designing for heat regime management of the premises consists of the following stages: collection and processing of output data including the research of the project documentation and the features of technological processes happened in the premises, development of possible exact imitating mathematical model of heat regime of the premises and the method of its realization using computer systems; evaluation of the influence of separate components of heat balance of the premises and different heat engineering parameters on the values of target function by the method of computer –

based experiment; development of the preliminary mathematical models for heat regime management of the premises taking into account the results of computer-based experiments; substantiation of the preliminary mathematical model on the basis of comparison of the results of calculations on this model with the results of calculations on the imitating mode; identification of mathematical model on the basis of the results of in-situ experiments; increase of adequacy of mathematical model in the process of its functioning.

The issues of ensuring of the required adequacy of mathematical model and object pose certain requirements on the main principles and stages of the constructed model. The model should be a simplified display of the real object as well as an adequate description of the properties to be considered. This is a contradictory requirement to some extent together with the wish to achieve absolute exactness of reproduction of the researched physical process which sometimes leads to serious errors allowed during the model development. In some cases, the model is created so bulky and complex that significant time is required for obtaining one realization. In these cases, computer can become unworkable due to the availability of hindrances and possible failures of the model. Therefore, it is necessary to go not through the complicated way and detailed description of the research subject, but through the way of proper technological succession of the model development in order to meet the requirements on the accuracy of modeling.

While elaborating an initial structure of the model on the basis of available priori information about the object and tasks of tests, it is necessary to be guided by the principle of creation of very simple structure. It can be achieved by proper approach to selection of relevant factors while appropriately choosing of more rational schemas for description of main correlations between the considered variables.

Preliminary mathematical model of heat regime of the premises represents in the most peculiar case a system of equations of heat balance of the indoor air (12.1), heat balance of the enclosing structure (12.2), heat balance of sports facilities located in the premises (12.3), heat balance of the equipment (12.4) and air balance of the premises (12.5) .

$$\sum_i Q_{c,i} + \sum_k Q_{tech.} + \sum_j Q_{a,j} = 0 \qquad (12.1)$$

$$\mathrm{Q_{str}} = 0 \qquad (12.2)$$

$$\mathrm{Q_h} = 0 \qquad (12.3)$$

$$\mathrm{Q_{pr}} = 0 \qquad (12.4)$$

$$\sum \mathrm{M_i} + \sum \mathrm{M_l} = 0 \qquad (12.5)$$

where $Q_{c,i}$ -convective heat transferred to the indoor air by the internal surface of the enclosing structure; $Q_{tech.}$ -convective heat transferred to the air of the premises from the technological equipment washed by this air; $Q_{a,j}$-convective heat transferred directly by the air of the premises, for example, from air con ditioning devices due to the filtration of outdoor air; M_i – air flows directly transferred to the premises or eliminated from it; M_l – air flows due to the filtration through the enclosing structure.

The system of equations (12.1) – (12.5) is interconnected and most be solved jointly. Let's consider the features of calculation of the components of heat and air balance of this system. Convective heat transferred to the indoor air from the internal surfaces of the enclosing structures is calculated from the system of equations of heat balance of these structures. Analysis of calculation algorithms of non-stationary heat regime shows that consuming of much computer-based time are associated with the solution of equation on heat conduction for the enclosing structures. Calculation of convective heat flow transferred to the air from the internal surface of the external enclosing structures with heat inertia less than 2.5 can be calculated by the following formula:

$$Q_c = a_c(t_{a.s} - t_a)F \qquad (12.6)$$

where $t_{a.s} = t_a + [(t_H - t_a) / R_0\alpha_B]$; $t_{a.s}$, t_a, t_H – the temperatures of the internal surface of the enclosing structure, internal and outdoor air, accordingly ° C; α_B, α_k-coefficients of heat exchange and convective heat exchange, accordingly W/(m^2 · °C); R_0 – the resistance of heat transfer of the structure, (m^2 · °C)/ W; F – the area of the enclosing structure washed by indoor air, m^2.

It is possible to use the ready-made solutions given in literature on the calculation of head conduction through constructions to calculate the convective heat flow transferred to air from the enclosing construction with any value of heat inertia. In this case, the bulkiness of solution is overcome by the circumstances under which both the values of heat engineering indicators of the enclosing constructions and the values of the coefficients of heat exchange on the surfaces are previously known. Putting these values in the relevant equation for the calculation of the internal surface temperature of enclosure, we receive a simple function depending on time.

The peculiarity of calculations of the internal surface temperature of enclosure by this function is in the fact that the appropriateness of changes of the outdoor air temperature is not known beforehand. In this case, initial classic solution should be taken for constant temperature of the outdoor air and the solution for the case of variable outdoor air temperature should be obtained using the Duhamel's theorem:

$$t_{a.s} = -\frac{\partial}{\partial T}\int_0^T t_H(T)t(T-\theta)dT \qquad (12.7)$$

where t(T -θ)-the function expressing of the internal surface temperature of enclosure under constant temperature of outdoor air received from initial classic solution by substitution of the known values of heat engineering indicators of the structure with coefficient of heat exchange °C; $t_H(T)$-function expressing of the outdoor air temperature obtained by one of methods of interpolation.

The convective heat transferred to the indoor air from the technological equipment includes the heat emitted by the people present in the premises taking into account intensiveness of their activity Q_p, the heat released from lighting installations Q_{lig}, the heat released from electric equipment present in the premises Q_{el}, the heat emitted from the equipment surface, for example air ducts of the heating system Q_{eq}, the heat released (heat loss) as a result of convective heat exchange between the surface of the artificial ice floe and indoor air Q_{ice}. The values of the heat emitted by the people depending on the intensiveness of their activity and the indoor air temperature are given in table 12.1.

Table 12.1 Heat release by adults (men)

Intensiveness of activity	**Heat release Q_p depending on the internal air temperature, ^{0}C**			
	15	**20**	**25**	**30**
Dormancy	100	75	50	35
Medium	110	90	60	35
High	140	110	80	35

It is admitted that women release averagely 85% and children 75% of the heat and the moisture released by men.

During determining the entrance of heat into the premises, it is considered that all energy consumed for lighting transforms to heat heating the ambient air, wherein a part of the energy heating the internal surface of the enclosing structures of building is neglected. If the lighting equipment and lamps are out of the premises (for example, beyond the glazed structures), the amount of the heat entered to the premises is determined on the sum of the radiation in visible and invisible parts of spectrum entered to the premises. For filament lamps having from 100 to 1000 watt capacity, the quantity of the visible radiation (light) is equal to 12% and the quantity of the invisible radiation is equal to

73.8%, the heat transferred to the air washing the lamps due to the convective heat exchange equals to 14.2%. For the luminescent lamps with 40 watt capacity the above stated values are equal to 16.5, 27.5 and 46%, accordingly. According to the experimental data, from the luminescent lamps installed in the garret floor of buildings having no lanterns 40% of heat enters to the premises and 60% to the garret floor.

Heat release from the surface of air ducts washed by the air of the premises is calculated according to the following formula:

$$Q_{pr} = (t_m - t_a)l/R_{air} \quad (12.8)$$

where t_m medium temperature of air duct lengthwise, °C; l-the length of the air duct, m; R_{air}-resistance of heat conduction of 1 m length of the air duct, m ·O\W.

The heat released as a result of the convective heat exchange between the surfaces of artificial ice floe and indoor air is calculated by the following formula:

$$Q_{ice} = (t_a - t_i)a_c F_i \quad (12.9)$$

where t_a, t_i-the temperatures of the indoor air and ice surface, °C; α_c-coefficient of convective heat exchange between the ice surface and indoor air, W/(m^2 · °C); F_i– the area of the ice surface, m^2.

The convective heat entered to the premises from the heat regime regu lation devices can be calculated as following:

For hot air heating (cooling):

$$Q = c_a \rho_a mV(t_a - t_i) \quad (12.10)$$

For radiators, heating panels, stoves and so on:

$$Q = a_c(t_a - t_i)F \ (12.11)$$

where c – the specific heat capacity of air, W·hour/(kg · °C); ρ_a – air density, kg/m^3; m-multiplicity of air circulation, l/hour; V-volume of the premises, m^3; t_a-temperature of delivered air according to formula (12.10) or temperature of the surface of the heating device according to formula (12.11); t_i -temperature of indoor air, °C; α_c-coefficient of convective heat transfer of the heating device, W/(m^2 · °C); F –heat transfer area of the heating device, m^2.

The convective heat entered to the premises as a result of the outdoor air infiltration is calculated by the following formula:

$$Q = cG_f(t_a - t_H) \quad (12.12)$$

where G_f – the amount of air entered to the premises due to the infiltration, kg/hour.

Air infiltration is considered for windows and doors located only in the windward side.

If the building is not divided into separate premises, the greatest values of air that determined during different wind directions are taken during infiltration calculation. If the building is divided into a number of premises, then air infiltration through the ledges is taken into account separately for each of them.

The prevailing wind directions for different territories are accepted according to the relevant data.

The quantity of air entered through fissures of ledges is determined by the following formula:

$$G = \sum(gla) \qquad (12.13)$$

where g-the quantity of air entered through 1m length of the fissures depending on the average wind speed within three coldest months (table 12.2), kg/hour; l -length of fissures of ledges, m; a-correcting coefficient of air infiltration depending on the character of ledges (the values are given below):

Fanlights of windows and lanterns with binders:
Single doors 1
Double doors 0,5
Single metallic 0,65
Double metallic 0,33
Doors and gates 2

Table 12.2 The quantity of air (g) infiltrated through 1 m length of the fissures depending on their width and wind speed

Kind of binding, the slit width	**Wind speed, m/s**				
	to 1	2	3	4	5
Metal, 1mm	3,8	6	7,4	8,4	11,8
Wood, 1,5 mm	5,6	9,1	11,2	12,6	17,5

The quantity of the outdoor air entered through the gates during their short-term opening can be determined by the following formula:

$$G = A + (a - kV)F \qquad (12.14)$$

where A, α – the coefficients of reflection of radiation and heat transfer; k – conditional coefficient equal to 0,25 for the gates of 3 x 3 m size and 0,2 for the gates of 4 x 4 m size; V-wind speed, m/sec; F-area of cross section of shaft and opened fanlights in lanterns, m^2.

For the premises of the equipped sports buildings the release or absorption of heat by mass of these devices significantly affects the heat balance. Significant amount of heating energy is saved due to the release of heat by mass of the equipment when the indoor air temperature in reduced at night time. Release or absorption of heat by the devices can be determined for the buildings with air heating by the following formula:

$$Q_{eq} = (t_a - t_{eq})l^{-kT}F_{eq} \quad (12.15)$$

where t_{eq}-the temperature of the equipment at initial moment of time before heating, °C; t_a – indoor air temperature after termination of heating, °C; k = αF/cG-time constant for the equipment, l/hour (c – specific heat capacity of the equipment W·hour/(kg·°C); G-mass of equipment, kg, related to the unit of the floor area, m^2; F_{eq} -floor area, m^2; α-coefficient of heat transfer of the equipment, W/(m^2 · °C).

The value of the heat transfer coefficient of the equipment is conditioned by the influence of the convective heat exchange occurred between the equipment surface and air, and the radiant heat exchange between the equipment surface and surrounding area.

The amount of the solar radiation heat entered to the premises of the building through filling of the light aperture can be determined according to formulas (7.39) – (7.40).

The mass of incoming air required according to the sanitary norms should be determined by the following formula taking into account the air entered to the premises due to infiltration:

$$G = G_f + m\rho V \quad (12.16)$$

where G-the mass of incoming air required according to the sanitary norms, kg/hour; G_f -air mass entered to the premises due to infiltration, kg/hour; m -multiplicity of air exchange, l/hour; ρ -air density, kg/m^3; V – the volume of premises, m^3.

For the premises with air heating system the quantity of heat consumed for heating of the inflowing air can be determined by the following formula:

$$Q = Gc\rho(t_i - t_o) \quad (12.17)$$

where t_o-the temperature of outdoor air, °C, t_i-temperature of inflowing air, °C.

Specific character of the use of formulas which include the outdoor air temperature first is in the fact that its values are not known previously and secondly, it is not periodically repetitive. At the present time, the methods of description of stationary processes by the models of auto-regression, sliding medium and mixed numbers and also by the chaotization method are used to forecast the process of change of real parameter. But they are difficult enough for use, as they require significant calculation. Let's suppose that the process of change of the outdoor air temperature can be considered in small time intervals like stationary and is introduced with a real random variable. In this case, the most closer approximation of the forecasted value of the outdoor air temperature t* (τ+Δτ) at the moment of (τ+Δτ) time to its real value t (τ_0 + Δτ) can be realized through selection of real coefficients ρ in the following com bination:

$$t^*(\tau_0 + \Delta\tau) = p_1 t(\tau_0 - 1) + p_2 t(\tau_0 - 2) + \cdots .. + p_n t(\tau_0 - n) \qquad (12.18)$$

Taking into account the non-stationarity of the process of the outdoor air temperature change, the selection of coefficients must be periodically renewed. The time interval during which the process is accepted as stationary depends on the heat inertia indicators of the enclosing construction and can be considered as equal to the value of delay in the temperature wave passage through the enclosure.

It is necessary to take into account unevenness of the indoor air tempe rature distribution in the horizontal and vertical space of the premises for the calculation of heat losses through the enclosing structure due to the air filtration and thermal conductivity. The task on use of extremely simple mathematical models of the heat regime of the premises makes the direct solution of the equation on convective heat exchange improper. Moreover, approximation methods of these equations solution are also inacceptable because of their complexity for the management tasks. It seems that the proper and effective way through which the unevenness of temperature distribution in the horizontal and vertical space should be based on the use of the experimental research results on the appropriateness of temperature fields' formation in certain class rooms. In this case, it is expedient to generalize the research results in the form of dimensionless temperature simplexes which are analogical on their structure to the temperature simplexes *m* applicable in the theory of hot workshops aeration. The values of dimensionless temperature simplexes are precisely determined during identification of mathematical models.

After choosing and substantiation of the mathematical model of heat regime of the premises, its identification stage, i.e. the stage of determination on the realization of input and output variables obtained under the object functioning condition the unknown or approximately given parameters of the model follows. Thus, basically the identification is an experimental method of concretization of the mathematical models of heat exchange in the premises on the input and output signals of the object. The measurability of input and output variables is the natural requirement of the identification resulted from abovementioned formulations. Input and output variables are measured during the object functioning covering the real range of changes of input variables and its condition. Wherein, it is not essential which signals (natural, specially prepared or artificial) are entered to the object, it is important that their measurement as the measurement of output signals is implemented synchronously under the object functioning conditions.

A number of essential requirements are derived from this provision and the tasks following from them, practical solution of which has primary importance, but unfortunately, is faced with a number of difficulties. The task of limiting the number of input variables to be included into consideration and determining an approximately specified target and the given output variables is posed in the first place. The solution of this task is determined by priory information about the object, but frequently, it is small for complex industrial object and doesn't give a possibility to establish exactly the necessary number of input parameters before the experiment. In most cases, this condition is caused by the fact that available equations of heat balance of premises describe the object well in ideal conditions, but gives significant errors in real industrial conditions. Thereby, estimation of the connection form between the input and output variables should be implemented on the realization of these values obtained under the object functioning.

The mathematical model of the heat regime of premises for the management from the viewpoint of their identification can be divided into two classes: mathematical model with removable informative uncertainty and mathematical models with irremovable informative uncertainty.

The task of identification for the first class mathematical models consists of the following. Let's suppose that there is an operator F unknown for us describing the object well enough. The problem is set: to select the operator F* being the exactest approximation of the operator F in the given class of mathematical models Ω according to the observations of input and output variables of *y*. Proximity of operators F and F* can be estimated by functional χ, minimum of which corresponds to the most adequacy of F and F*, i.e. the task of identification has the following form:

$$\min\chi[F, F^*] \rightarrow F^* \in \Omega \qquad (12.19)$$

As the operator F is unknown, the requirement on adequacy of operators F and F* is substituted by the requirement of adequacy of input parameters for the object and its mathematical model F*, i.e. the identification task takes the following form:

$$\chi(y, y^*) \rightarrow \min, \tag{12.20}$$

where *y** is determined by the model F*.

If there are rather complete data on input parameters *x* and *y* and reliable information about the form of analytical dependence $F^* \in \Omega$, then the theo retical basis of identification of technological processes [28] elaborated to date allows establishing adequate models among the functions of F* (xβ) differing from each other only by the vectors of parameters $\beta = \beta_1, \beta_2, ...\beta_n$ through the choice of parameters β_i. The methods of linear identification, least squares and algorithms of regression and correlations analyses have been widely used up to the present time. It is obvious that parameters of β_i can be determined by different ways depending on the criterion adopted for the characterization of "the best" values of parameters. In the considered task of identification of the mathematical model of heat regime of the premises by the basic criterion through which the results of forecasting of the heat regime formation of the premises can be estimated are the forecast accuracy that greatly depends on the exactness of determination of unknown parameters of β. Thereby, parameters of β should be determined so that the forecast error would be minimum. Herewith, taking into account the specification of the solved problem, it is possible to make the following requirements to the method of determination of β parameters: universality in the meaning of acceptability for identification of all or most types of the elements of the premises, simplicity and reliability, as well as precision enough for practice. The analysis of the theoretical methods used during identification showed that the method of maximum probability meets the stated requirements more completely. The main idea of the method is the determination of so called likelihood function – conditional density probability connecting unknown parameter with the experiment results.

After determination of the probability function, it is maximized with respect to unknown desired parameter. The method of maximum probability gives asymptotical estimation, i.e. the estimations which efficiency tends to one under unlimited increase of observations number. Simplified method of the unknown parameters determination-the method of the least squares is also recommended. In this case, its essence is to minimize the sum of deviation squares of the process' determined basis estimation from available statistic data. So, if Y=f(a, x) η, then the estimations of unknown parameter $\bar{a}$, is found from the following formula:

$$\sum_i [Y - f(\bar{a}, \bar{x}_i)]^2 = \min \quad (12.21)$$

As it is stated in (12.21), all observations of Y_i are accepted with equal weight when using the method of the least squares.

It is expedient to implement the identification of mathematical model in two stages. In the first stage, individual elements, for example, heat and solar control indicators of the enclosing structures, air permeability of both the enclosing elements and the premises entirely, as well as technological heat release and the characters of temperature fields' distribution in the air medium of the premises are indentified. In the second stage, the mathematical model of the premises as a whole is identified under different dynamic regimes. This should include also series of calculations in the range of possible changes of parameters to determine their relevant contribution to the formation of heat regime of the premises.

The mathematical model of the heat regime of premises with irremovable informative uncertainty with respect to features and behavior of the object, conditioned by the dynamicity of the phenomena and the external factors not taken into account is lawful only in the cases if the accumulated information doesn't eliminate available uncertainty and the objects behave in the unanti cipated manner. Then, identification as the stage of solution of the management task loses its practical sense. Indeed, any model received at any time doesn't correspond to the object correspond with a high probability even in the short time. The greater is this probability, the longer is the process of identification requiring significant time depending on the complexity of the object.

While solving the problem under described conditions, modern cybernetics suggests the use of so called algorithms of self-organization having maximum ability to adapt to the object changes. It is not enough to study certain para meters, maximum varying the width of class Ω and use current information in accordance with one or another algorithm of adaptation in order to synthesize adequate models. It is necessary to pass from one class of model to another one, i.e. to change the organization of the algorithm of adaptation-its structure and functioning at the right moment.

12.5. The functions of operator in the automated management system

In the automated management system of microclimate of the sports facilities, the operator must obtain the information characterizing the course of the microclimate formation process and have the opportunity to influence it through the management system. Controlling the course of the process, control computer must give the results of control to the operator, and in a number of cases to advise on how to conduct the process in a given situation. In order to implement the mentioned requirements, the control computer should have special equipment-console supplying the operator with a visual representation of information and allowing to influence the course of the process microclimate formation of the constructions or their separate parts.

The operator realizes the following main functions: centralized control of the object parameters and fault of the system formation and information transfer; activation of the warning and alarm signals during the relevant con ditions in the object; documenting the object's management process; change of the system operation and influence on the course of the processes happened in the object.

Centralized control includes periodical registration of parameters on the established list, registration of the group of parameters or one parameter on the operator's call, registration of deviations of the parameters, registration of all the operator actions in the console (management protocol). In this case, registration of the parameters called by the operator, changes in commands and coefficients made by them, action of the operator upon acknowledgment of deviation and emergency signals, pressing the buttons, removal of managing signals from the control computer, turning on and off of the operator console is implemented.

For convenient work of the operator all the data entered into the system from the console and derivable to the console or print should be presented in decimal form. The language of interaction of the operator with the system should contain the numbers of the operation or commands implemented by control computers according to the operator's instruction and the numbers (addresses) of the parameters, indexes or coefficients entered into the control computer or delivered to the console. This language should provide introduction of the values of the object parameters and other data in engineering units corresponding to the physical meaning of the given parameter.

A number of indicators each of which shall be taken for alarm signaling in the nods of the system are placed on the alarm panel to submit the centralized control results on the object parameters as well as the control results on the working ability of all system and the detected emergencies to the operator. Two other indicators intended for alarm signalization indicating the deviation of parameters with respect to their preset values also correspond to these nods.

During elaboration of the centralized control algorithm, the controlled para meters of the object should join together in groups. Each device alarming emergencies and two devices informing the deviations related to them are intended for separate groups of parameters which alert about the deviations of one or several of them from the permissible limits. The light indication must be accompanied with the voice signalization in case of overrunning of warning and alarming installations as well as during the emergencies in the nods of the system. Wherein, the bleeper should sound uninterruptedly in the emergency cases and in a broken manner in other cases.

The operator must be given the opportunity to acknowledge the noticed indicators, for which all of the alarming devices should be done in the form of buttons with illumination. Pressing the buttons of the device by the operator serves as the acknowledgement of signal. The acoustic alarm is turned off according to this signal and the data on the value and address of the deviated parameter are introduced on the digital display panel.

The Joint work of the operator and control computer takes place in a mode “request - response”. It means that after the issuance of the task the operator must wait for the response from the control computer, and only after that a new task can be given. Having received signal on the data input, control computer not only realizes their acceptance, but outputs the received information back to the control panel. In the control panel this information is compared with the information collected in the switchboard. This comparison is implemented automatically with apparatus of control panel generating backward signal to the control computer about coincidence of the information introduced in the control computer with the information set in the control panel. If there is not this coincidence, the indicator “incorrect input” illuminates. In case of the information coincidence, the operator receives a signal “imple ment the operation” that is stored within all time of implementation of the given operation. When typing in the control panel improper operation or address, a special indicator lights up after pressing the "execution" button.

Documentation of the management process and all operations implemented in the control panel is carried out using the printing apparatus where the following actions are implemented: periodical printing of a set of the registered parameters; registration of deviation of parameters from the permissible limits and emergency cases; printing of all installations, indicators and coefficients which were changed by the operator or control computer the process of system’s operation; registration of all actions of the operator in the control panel including the titles and values of parameters called by the operator for the acknowled gement of the deviation and emergencies signals, disconnecting the control of the control computer and switching the control panel, etc. The time of data input must be noted during periodical printing of the group of parameters as well as at the beginning of input of other data for the registration. The value of parameters shall be printed with red paints in case of accidental deviations and error in the actions of the operator. Documentation of the deviations of specifically responsible parameters should be accompanied with printing of the data on the values of the given parameter setting.

The availability of appropriate software is of great importance for normal functioning of the operator's control panel as well as for facilitation of interaction between the operator and the control computer. It should consist of the programs necessary for implementation of the abovementioned functions. Besides, the software should have a program for textual control of the equipment of the operator's control panel allowing to control automatically the work ability of the apparatus used in the panel upon the command of the operator. These controls are divided into independent stages, which the operator can give to the control computer from the control panel introducing relevant operations. Textual control of the apparatus of the panel acts cyclically and is carried out until the operator gives command on the implementation of new operation to be perceived by the control computer as a command for stopping the previous operation. All programs forming the software of the operator's control panel include subprograms intended for realization of different forms of control of the information introduced by the operator and logicality of the operator actions during delivery of task to the control computer. These sub programs don't allow the operator to premeditatedly or accidentally damage the programs and other data saved in the memory devices of the control computer.

12.6. Recommendations on the introduction of the automated microclimate management system of sports facilities

It is expedient to establish automated microclimate management system of the sports facilities so that it could be able to begin its functioning with small scale of automation and simplified mathematical software. Afterwards, the system will be gradually developed and complicated both on the automation functions and by complete consideration the building's heat process in the mathematical model. Five structure types of industrial control distinguished by the characters of the management function can be separated out depending on the method of introduction of the computer into the control loop.

Computer system in the mode of data collection and processing. Parameters of engineering processes EP, measured by sensors S are transformed into digital forms by means of conjugation and introduced into the computer. After processing in the computer the operative data about the course of the process enter to the technological parameters reflecting device; statistic information intended for registration, as well as calculated economical and technological indicators are printed in the form of report (document), and the data which can be used later in the calculations are usually fixed in magnetic carriers - punched tapes, punch cards, magnetic discs and so on.

The system of collection and processing of data mainly implements the same functions as the centralized control system being higher level of their organization. Therefore, difference between these systems is of qualitative character. Computer gives great opportunities for mathematical processing of data.

Computer system in the adviser mode. Along with the data collection and processing, the following functions are also implemented in such kind of systems: determination of a rational technological mode on different technological parameters or all processes as a whole; determination of the effects of control on all or individual controlled variables of the process; determination of the values of local regulators adjustments.

In the adviser systems the data on the technological mode and control influences enters through the data representing (reflecting) device in the form of recommendations to the operator which can be accepted or rejected. The decision of the operator is based on his own understanding of the course of the technological process and experience on their management.

Computer system in the mode of supervisory control. AMS TP functioning in the mode of supervisory control is a two-level hierarchic system. The lower level directly connected with the process forms local regulator of different engineering parameters. The main function of the computer is installed on the upper management level is the determination of optimal technological mode and the calculation of the values of adjustments (settings) of the local regulators on its basis. The values of some controlled parameters measured by the sensors of regulators and the controlled parameters of the process condition measured by sensors are the inlet information for calculation of settings. The operator has a possibility of introducing additional information, particularly, changing the limits of both the controlled and controlling variables as well as specifying the control criterion depending on the external factors through the control panel.

The supervisory mode allows realizing automated control of the process. The role of the operator is the observation of the process and correction of the management goal and the restrictions on variables, if necessary.

Computer system in the mode of direct digital control. Differing from supervisory management during direct digital management the effects of control is calculated by computers and delivered directly to the executive organs. The of direct digital management mode allows to exclude local regu lators with specified settings. Like in the supervisory management, the functions of the operator in this mode are the observation of the process course and its correction, if necessary.

Hierarchic management systems. If one level structure of AMS TP doesn't provide the required mode of difficult technological object functioning, then the control system can be developed as multi-level-in the form of separate subsystems between which collateral subordination is established. Each sub system has a computer working in one of above mentioned modes.

In the first stage of the system input, it is necessary to exploit it according to the open-ended management scheme. In this mode, the control computer processes all measured information entered from the controlled object. Optimization is made by special programs and the recommendations on the appropriate ways of the controlling of mechanisms to achieve the preset mode are given. The maintaining staff follows these recommendations during the work implementation. The operation of the control computer in the adviser mode must start with turning to a closed control circuit.

Experimental examination of the efficiency of measures taken in the project for protection of communication lines from interferences should be provided when introducing AMS. In order to examine the correctness of communication lines performance and the rationality of technical means used in them for the protection of equipment from interferences specific local sources of obstacles as well as most useful places for laying cables should be determined in the object. After installing the control computer and mounting the communication system, it is necessary to precise the maximum levels of obstacles in each signal transmission channel and to determine the necessity of additional measures against interferences to ensure normal work of these channels.

The methods of testing of the steadiness of communication facilities to interferences should envisage two stages: testing without any control computer (statistic mode of measurement of parameters) and with a control computer (dynamic mode of testing with transfer of information to the system). In these tests it is necessary to control the correctness of conjugation of different devices including the connecting communication lines and the efficiency of their screening; research into the influence of different methods of screens grounding the coefficients of interference suppression in the signal transmission channels, to choose the best combination of grounding of screens and channel chains. It is also necessary to implement testing of signal transmission channels on the availability of cross interferences in the communication lines and also in the cables connecting the devices of the control computer and to remove the interferences caused by the presence of electric and magnetic fields in the premises where the control computer is installed.

Dynamic test should be carried out in the mode of management of the equipment of the microclimate formation system of the sports facilities. In this mode, the interaction of the control computer device with the sensors, executive units and the operator's control panel in real time scale, the steadiness of the signal transmission channels to interferences and the working ability of the system during feed voltage change are examined. In addition, the effi ciency of technical means used for interferences suppression in the dynamic mode of the system operation under the change information in the signal transmission channels is studied. These tests allow improving the mathematical software developed specially for the introduced management system and making necessary corrections in it.

As a result of statistic and dynamic tests, the final version of channels implementation in the system is determined and additional measures on protection against interference are developed.

The features of the control object and the role of the operator in the system must be taken into account when designing the work place of the operator and the control panel. All control elements (organs) and indicators reflecting the information corresponding to main functions of the algorithm of work of the automated management system of thermal conditions should be placed in the main working zone of the operator. The control tools must be placed so that to exclude erroneous actions of the operator and provide maximum convenience of their use. The facilities implementing contrary actions should be spatially separated and differed by their form and color. Information reflecting indicators should be placed so that the operator shifted his attention more rarely while passing from one indicator to other one. Coding of information on the indicators of the same type should be identical. It is necessary to concentrate in one place the control tools and information reflecting indicators set for one task.

During designing symbolic circuit, which reflects the structure of the object and highlights the state of its elements and all main characteristics of the process of the thermal conditions formation, it is important to determine correctly the sizes of devices placed in it. It is especially important to choose the form of indicators correctly while developing symbolic circuit. Each symbol of the circuit must unambiguously direct the operator to certain element of the object structure, and the normal sign must differ from accidental sign. The use of the indicators in red color for reflecting information about emergencies, the indicators in white color for information about readiness and the indicators in green color for the thermal conditions formation is preferred.

13. SPORTS FACILITIES

The sport complex built in the capital of Azerbaijan – Baku city is one of the largest universal facilities in the Southern Caucasus. This region is charac terized by dry semi-desert climate with hot summer and mild winter. The strong northern winds with 40 – 50% recurrence are the main distinguishing feature of the region. The winds with 6-9m/sec speed dominate. Storm winds with 30-40 m/sec speed are observed practically every month and continue for several days. The average monthly temperature in July is 25 ºC, and the average maximum value reaches 42ºC. The relative air humidity is 65-75%, atmospheric precipitations don't exceed 320 mm /year [60].

According to the design, the power consumption for the complex functioning is 100Gcal /year that is equivalent to the power consumption of the modern residential massive. The researches carried out on the optimization of power consumption of sports complexes showed that it is possible to save 30-35% energy through implementation of a number of measures during designing and exploitation of the object. They include: analysis of the impact of climatic conditions on the complex and substantiation of the choice of their calculation values; optimization of architectural and construction decision of the sports complex as a whole and its individual parts on the basis of physical modeling of aerodynamic and temperature conditions of the construction; optimization of heat and solar protection of the external enclosures based on the mathematical modeling of the building's heat balance and optimization of power consumption using the automated management and control system of technological processes.

The sports complex constructed in Baku city includes the building of the Sport Palace, medical rehabilitation center, recreation center of 45 ha area, planar sports grounds including tennis stadium with 14 tennis courts, perfor mance areas with 800 seats, volleyball and basketball pitches, swimming bath and swimming pools, and the racing track made of synthetic covering.

The Sport Palace is designed for holding the international, regional and local competitions. It is also a suitable place for the organization of important cultural and political events and exhibitions. The main demonstration hall is considered for 8 thousand seats with the possibility of increase after transformation of the arena to 10 or 12 thousand seats. The Palace is intended for the competitions on ice hockey, tennis, handball, gymnastics, box and wrestling, weightlifting, basketball and volleyball, track and field athletics, as well as demonstration of films, spectacles and ice ballet.

The Sport Palace is the center of compositions of all sport complexes. It consists of two parts including the main demonstration part designed in round form with 122 m diameter of the lower part and the training halls. Both parts are connected with intermediate block.

The building has protective elements preventing direct entrance of solar radiation into the premises (see chapter 3) and reducing wind effect (see chapter 2). Special solar control glass –"traflex" is used as additional means allowing to reduce insolation.

The medical rehabilitation center is located in the northern part of the territory. The building is designed in the form of enclosed space with internal yard and the territories in the side of sport park. Taking into account the climatic peculiarities of the territory, one – sided orientation of working rooms was designed on the basis of the calculation of insolation. The complex relief of the area conditioned little number of floors of the building (3-5 floors). The center includes: complex of medical pools, halls of therapeutic physical training, block of hydrotherapeutic procedures, dry heat baths, medical cabinets and laboratories, hospitals for 30 beds.

The recreation complex occupies 25 ha area abundantly planted with greens (70% of the area) that contributes to biological cleaning of the territory. The ornamental quality of plants (color and form of crown, summer and winter silhouettes), character and blossom time and the ability to make shadow and protect against wind were taken into account during selection of the plantation assortments.

Cycle track is located close by the Sport Palace and occupies 20 ha area. Unfavorable conditions associated with poor wind and thermal conditions were observed repeatedly during its exploitation.

In-situ microclimate researches were implemented in 12 points of the cycle track to eliminate these phenomena (picture 13.1).

The following parameters were studied: wind speed was determined using cup anemometer, the temperature of the surface of the concrete road-bed was determined by special thermo-probe instrument ETP-2, solar radiation intensity was determined by pyranometer coupled with galvanometer. The results derived from the researches (see table 13.1 – 13.3) allow to conclude:

1. *The object is characterized by high speed of air flow at the height of 1,5 meter from the cover surface with respect to the speed of air flow near the cycle track.*

2. *High speeds of incident flows negatively affect the mood of sportsmen, at the same time impedes speed acceleration when running on the track.*
3. *The speed of air flow is especially high in the points from 1 to 6.*
4. *Deceleration of air flow speed almost not occurred in point 8 compared to "undisturbed" flow in points 1, 4, 5 and 6. Consequently, while reaching high values of air speed in points 1, 4, 5 and 6 analogical values of are observed also in points 7, 8 and 10 that can cause significant difficulties during the competitions.*

Table 13.1 Temperature of the surface of the cycle track road-bed, °C

The number of measurement points	Time of day				
	10.30	12.00	14.30	16.00	17.30
7	29,7	33,5	41,5	39,5	37,5
8	30,5	37	38,5	39,3	36,5
9	32	37,5	42	44	40
10	27,5	33	36,7	39	37
11	26,5	30	37	39,8	36
12	27	31,5	35	34,5	32,5

Pic. 13.1 The scheme of the cycle track

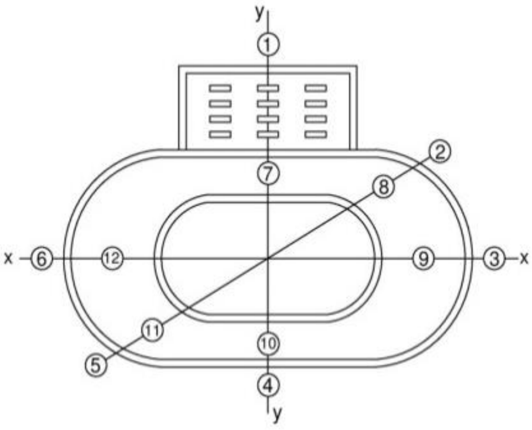


Table 13.2 Solar radiation intensity, W/m^2

The number of measurement points	Time of day				
	11.30	12.45	14.30	16.00	17.30
7	733	895	813	593	367
8	909	974	724	451	232
9	867	1066	928	782	578
10	668	772	791	603	493
11	442	590	751	530	513
12	410	517	442	238	214

Table 13.3 Wind speed, m/sec

The number of measurement points	Time of day				
	11.30	12.00	14.30	16.00	17.30
1	3,4	2,6	4,2	4,5	2,3
2	3,1	2,3	4,1	4,2	2,1
3	3,7	2,8	4,5	4,7	2,5
4	2,9	2,3	4	4	2
5	3,4	2,5	4,1	4,4	2,2
6	2,7	2,1	3,7	3,8	2
7	2,2	2,5	2,1	2,6	1,6
8	2,2	2,5	1,8	1,6	0,8
9	2	1,6	1,7	2,2	1
10	2,7	3,1	1,7	1,8	2,2
11	1,5	1,6	0,9	0,9	1,5
12	0,8	1,8	1,7	1,05	0,8

Consequently, in order to provide normal exploitation of the object it is necessary to slow down the speed of the incoming air flow to the athlete during his movement on the track. This can be realized by several methods including:

a) *increase of the height of the wooden board bordering the cycle track up top 1,5 m;*

b) *alignment of the wooden board height at point 10 with the height of the board in points 2, 3, 5, 6.*

c) *plantation of greenery in the territory of the cycle track which will provide deceleration of the air flow negatively affecting the athletes.*

Another factor affecting the condition of the road-bed of the cycle track and consequently, on the possibility of reaching high speed in the competitions is the temperature of the surface of the road-bed of the cycle track. The surface of the road-bed is heated up to high temperature during high radiation levels: under 28 ºC the temperature of the surface in different points reaches 44 ºC (point 9) and 41, 5ºC (point 7). Such kind of overheating negatively affects the state of the covering when it is periodically watered with cold water. It can cause cracking and destruction of the road-bed eventually. Therefore, it is expedient to water the cycle track between 07.00 and 07.30 in the morning and between 20.00 and 20.30 in the evening.

Pic. 13.2 A scheme of the athletics arena

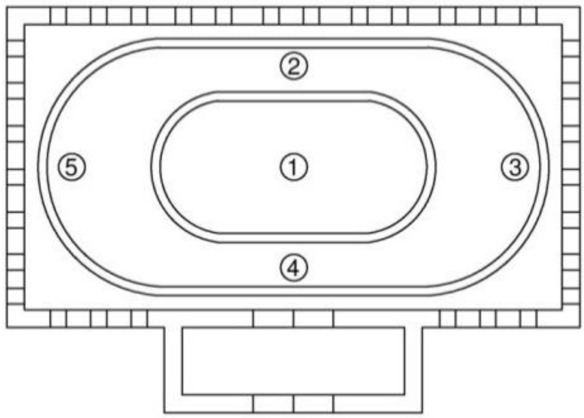


Table 13.4 Temperature and relative humidity of the indoor air

Number of Observation points	Time of day									
	10.30		12.00		13.30		15.00		16.30	
	t,°C	φ,%	t,°C	φ,%	t,°C	φ,%	t,°C	φ,%	t,°C	φ,%
1	28,8	63	28,8	60	29	60	29	59	28,9	60
2	28,8	63	28,7	59	28,8	58	29,2	59	28,9	61
3	29	61	28,8	58	28,9	58	29,5	60	29,1	62
4	29	61	29,9	59	29,1	59	29,5	59	29,2	60
5	28,8	62	30,1	60	29,2	59	29,8	60	29,2	61

Moreover, it is recommended to close the road-bed with metalized poly ethylene film or textile (sackcloth) during maximum influence of the solar radiation and high temperature of the outdoor air.

Table 13.5 Values of the measured parameters of the competition hall

Parameters	Time of day				
	10.30	12.00	13.30	15.00	16.30
Wall surface temperature at the point 2, °C	27,5	27,5	27,5	27,6	27,6
Mobility of air in the center of the hall, m/s	0,08	0,1	0,05	0,15	0,17
Wall surface temperature at the point 6, °C	28	28	28,2	28,4	28
Air velocity outside the building, m/s	2,8	4,9	4,5	4,0	5,9
The intensity of the incident solar radiation, Watt/m^2	641	553	560	809	581
Floor surface temperature at a point 1, °C	27,4	27,7	27,7	27,6	27,8

The athletics arena in the layout has rectangle form with 126 x 30 m size. The main premise is the competition hall having three running tracks with artificial coating "Spartan". The hall is equipped with the supply and exhaust ventilation system. During the research of thermal air conditions of the object, the main measurements were carried out on the competition hall. Temperature and relevant humidity inside the premises were identified in the characteristic points during in-situ observations (see picture 13.2 and table 13.4). In addition, air mobility was identified in the center of the hall at the 1,5 m height from the floor. Also, the temperature of the internal wall surfaces of the arena, the out door air speed, the temperature of the floor surface and the intensities of the solar and penetrating radiations were measured (table 13.5).

The implemented complex in-situ researches confirmed the correctness of theoretical conclusions about the possibility of provision enough comfortable thermal conditions without using air conditioning system in the warm period of year. For this purpose, the arena is supplied with high efficient solar control (picture 13.2) excluding of the direct solar radiation penetration into the premises. The multiplicity factor of air exchange is 10 l/hour at night and 4 l/hour in the daytime (from 10.00 to 17.00). Such kind of aeration conditions provides cooling of the premises by the cool night air and excludes overheating in hot daytime. Analogical solar control devices are used during the construction of the stadium for hand games and sports hall of "Neftchi" base.

Thereby, complex of measures (*architectural-planning design of the building, availability of solar control devices, as well as optimal air conditions found on the basis of theoretical and experimental data*) allowed to establish comfortable microclimate inside the arena. Practice shows that the efficiency of exploitation of the indoor sports facilities under the hot climate condition of the southern regions is significantly higher in the summer period than in the winter. It is conditioned by the fact that high temperature (table 5.1) and radiation in the open areas causes additional load on the sportsmen organism.

13.1. The use of the methodology of systems approach to the designing and construction of sports and recreation complexes

At the present time, designing of complex sport and recreation facilities is realized in two stages: first-technical task (or engineering design) and second – working drawings. Technical task is developed for the purpose of determination of main design decisions and main technical – economical indicators of the system. The stage of technical task includes implementation of researches, experimental and development works. The technical task on designing is prepared taking into account the designs on regional planning, as well as designs on planning and construction of cities and rural settlements. Sportive technologist on physical training plays an important role in its preparation. The technical task should reflect: the data on the quantity and contingent of sports men and physical trainers for whom this sports complex is destined; a list of main and auxiliary facilities and the facilities for audience; the carrying capacity of these facilities and the data about the construction area.

All architectural-planning issues and engineering decisions are developed at the technical task stage. Based on the available financial opportunities the cost of construction is estimated and the issues on provision of construction with materials, equipment and working power are developed. The technical task is approved by relevant architectural and planning body and affirmed by financing authority. Afterwards, working drawings are developed.

Site selection for the construction designed at the stage of technical task development is implemented taking into account three groups of requirement:

- *physical culture, technical and sanitary-hygienic (selection of the most favorable site for sports from the viewpoint of the original relief of the terrain, climatic conditions and remoteness from the sources of dust and polluted air);*
- *economical (closeness of power sources, water supply, sewerage, availability of local construction materials, closeness and ease of the delivery of equipment, constructions and materials)*
- *construction and technical (dryness and not flooding of the area, the level of ground waters, good ventilation of the area and so on).*

Development of a scientifically substantiated technical task is the most important stage of the construction designing. The methodology of this stage development is increasingly attracting the attention of specialists from all over the world from year to year. For example, these issues took central place in the global congress “KLIMA 2000” dedicated to construction problems which held in Denmark in 1985. The reports presented at the Congress by the leading specialists from USA, Europe and other countries addressed the issues related to the use of systematic analysis in building design and designing strategy optimization. The methods of overcoming uncertainty and inconsistency of goals and the development of the construction projects on the basis of experiments and test results were also highlighted. Interest in the first stage of the construction design was specially exacerbated due to introduction of the latest achievements of scientific – technical progress and in particular, automation of designing during elaboration of the working draft.

One of the main difficulties appeared during development of complex building project, especially of such kind of voluminous project of sports and recreation complex, is that much information is needed for its design. Information sources are a lot, and the form of information supply is different. It includes climatic information and geophysical data about the supposed cons truction place as well as the information about the technical and techno-economical characters of the future facilities and about the means of these characteristics achievements. The specification of information is conditioned with the sports aspect of the facility regarding the large dimensions of the objects, their load specifics in the day and night times, the complexity of the facility where courts, closed halls, arenas, closed and open swimming pools are combined. The issues related to comfort, conditioning and ventilation of sports facilities require additional information.

General information flow used directly in the designing process must include the information obtained during experimental modeling of objects and construction – physical processes (physical and mathematical modeling using computers). An important feature of the development of complex cons truction facilities as well as sports complexes is the necessity of combination and coordination of the efforts of specialists from different scientific profiles, so, unification and concordance of the used information.

The problem of development of the scientifically proven technical task is the nodal problem of designing. Today, its successful solution (acceptance of optimal version under excessive information and coordination of activities of specialist from different fields when, if necessary) is possible only on the basis of systems approach and use of systematic analysis. One of distinctive features of the latter as a scientific research method is the combination of unformalized analysis methods (for example, experiment, physical modeling, heuristic devices, experts opinion and so on) with strictly formalized mathematical methods (mathematical calculations and mathematical modeling using computer) during the process of adoption of optimal decision.

Systematic consideration of the object during designing supposes the realization of some fundamental principles. Firstly, systems approach to a complex design (just such is the design sports and fitness center) requires subdivision of the design process into the design of individual subsystems, objects and aggregates; segregation of duties between different constructors, designers and researchers-calculators (decomposition principle). This principle is the reflection of objective realities of the design process. Regardless of the extent of their knowledge, every individual executer can operate only with relatively small amount of data. In each separate case, hierarchic structure of the project, the internal relations between separate components are determined by the specificity of the designed object as well as by the general designing strategy. The primary task of the hierarchical organization of the project is the distribution of information processing functions and decision making between individual elements of the system. If the scope of the information needed for both the system description and decision making is not significant, then there is no need for the hierarchical structure.

However, as practice shows, designing and optimization of a subsystem directly separated from the entire system is not possible. By this way, we can't obtain neither optimal subsystem, nor optimal entire system. Therefore, the second principle of the systems approach is the principle of the external completion. It consists in the examination of interconnection of the system with its surroundings. In other words, the system analysis supposes the necessity of consideration of each object as a part of a large system in which it is included and the solution of all the problems from the position of this system. Particularly, the analysis of the sports facilities microclimate is associated with the necessity of revealing its interconnections as the subsystem of the general project of a sports and recreation complex with other subsystems of the project, because the development of a scientifically substantiated methodology of designing is possible only on this basis.

Today, the system principle of designing is realized not as the spontaneous creativity of the designer or engineer, but as a purposeful algorithm. Both general theory and big number of practical methods reflecting the designing strategy and algorithm were within the framework of the systems approach.

Other fundamental principles of the systems approach are the principle of optimality and modeling. The principle of optimality consists in the comparison of the indicators of several design version and selection of the best. If the considered system includes a number of subsystems, optimization of the design decision of each of them should be conducted, i.e. the decision optimization is carried out during the process of system analysis of the object as well as determination and formulation of the purposes of subsystems and system as a whole.

Various imitation systems – mathematical and physical modeling of the object and its separate components play an important role in the modern designing on the basis of the modeling principle during assessment of the optimality. Imitation systems allow to compare the options and to choose the best. Generally, the imitation system is the mathematical or physical analogue of the object or its subsystems, however, the imitation experiment is considerably cheaper and quicker than in-situ experiment. Imitation systems based on the mathematical modeling are also used during construction of automated regulation system of the technological processes.

In its most general form, during consideration of the object as a whole or its separate subsystems the systems approach supposes the realization of the following designing strategies:

- *stage of the system analysis (selection of the basic subsystems, formulation of main requirements to them, i.e. the complex of requirements on the system as a whole);*
- *synthesis stage (reconstitution of the systems though connection of separate subsystems taking into account their features revealed during the analysis stage, working out of alternative decisions);*
- *stage of options estimation of and choice of optimal decisions.*

The followings are necessary to carry out this designing strategy:

information and regulatory-reference provision;

- *mathematical software provision (modeling mathematical programs for computers);*
- *provision of technical means (computer, modeling physical devices).*

Informational provision is of great importance when implementing the first stage of-system analysis. Two other types of provision are necessary in the third stage for choosing the optimal variant. We can say that the complexity of the designed object and its subsystems require preliminary creation of the modeling systems for choosing the optimal variants. And the modeling system concept must be understood as widely as possible: from the simplest test or calculation method up to the mathematical modeling carried out through complex algorithms and computer programs. The following consideration should be the criterion in the choice of modeling method: the accuracy of the obtained results should not be higher than needed to distinguish an acceptable decision from unacceptable one.

During development of the technical task on designing of the sports and recreation complex on the top floor of the hierarchical structure of the project, it is expedient to select 5 main subsystems including:

- *External environment of the sports and fitness complex;*
- *Internal environment of the sports facilities of the complex;*

- *Engineering system of the sports facilities and complexes as a whole;*
- *Building constructions;*
- *Organization of the construction.*

At this level of system decomposition the formation of objectives to the subsystems in essence means the concretization of general targets to the entire project. Consideration of interconnections between different subsystems of the sports and recreation complex shows the following: subsystem – outside environment can be practically considered separately, because any other subsystem doesn't influence it substantially. On the contrary, all other subsystems are dependent on the outside environment (more precisely, on the outside microclimate of the sports complex). The subsystem – inside environment is determined by other subsystems of the project. Central circumference unites the parts of three different subsystems: inside environment of the sports facilities, engineering systems and building constructions and determines a qualitatively new aggregate-a subsystem providing the normative parameters of the indoor microclimate.

13.2. Elaboration of the issues for providing normative microclimate parameters during sports and recreation complexes designing

Sportive-technological and sanitary-hygienic requirements (requirements on the microclimate of physical training and sports places) are the most important functional requirements among various requirements to the sports facilities.

Sportive engineering requirements arise from the methods of conducting exercises and trainings. They include: dimensions of training places, character of coating, capacity and so on. Sanitary-hygienic requirements determine the conditions of interactions of the organism of sportsmen and physical trainers with the environment. These requirements are underlain on the basis of normalization of main microclimatic factors influencing the health safety and strengthening, such as: temperature, humidity, radiant heat input and air dustiness, etc.

It is clear that sports and physical training is not possible without imple mentation of these two groups of requirements. Among other requirements to the sports and recreation complexes as well as individual facilities special attention should be paid to the followings:

- *Space and planning requirements;*
- *Architectural and artistic requirements (requirements to architectural and decorative design that is determined by both the building's category defining*

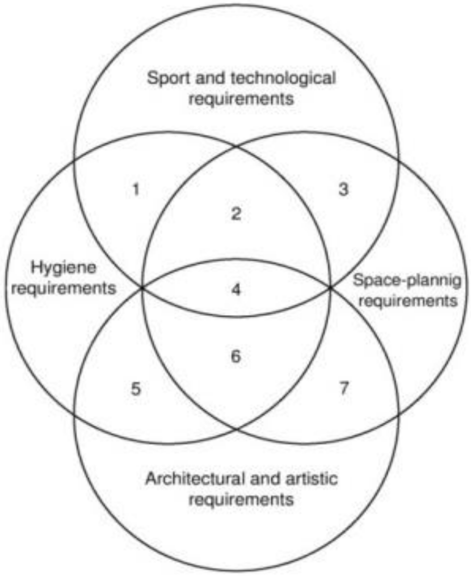
the limits of the use of architectural-decorative means and the local conditions including availability of materials, economical possibilities and so on).

- *Fire-prevention requirements (determine design solutions from view points of availability of evacuation ways, choice of construction and decoration materials).*
- *Constructional requirements (requirements to individual constructions of sports facilities: strength, longevity and efficiency, etc).*
- *Engineering requirements (requirements to sanitary engineering, electrotechnical and other equipment).*
- *Technique-economical and exploitation requirements (their implementation must ensure high efficiency of use of facilities, their profitability and recoupment).*
- *Typological requirements (determine the type and dimensions of the facility).*

The functional requirements to sports and fitness complexes are presented in the form of graphic models in picture 14.1. The followings are accepted as the basic functional requirements: space-planning, architectural and decorative, sports and technology and sanitary and hygienic (requirements to surrounding microclimate environment). Intersection of many requirements leads to the emergence of other requirements to the sports and recreation complex as the designing object. For example, aesthetic requirements appear as intersection of many architectural and decorative and space-planning requirements; the types and sizes of facilities (typological requirements) are determined by sports – technological and space-planning requirements. In this complex of requirements, the fundamental place belongs to the requirements to microclimate of facilities (sanitary and hygienic requirements). Indeed, the intersection of the latter with sports and technology requirements determines the throughput of facilities and the intersection with architectural and decorative requirements generates the requirements to the natural lighting design. The placement of engineering equipment, mounting of air distribution devices of the ventilation system, the requirements to the filler structures (walling) of facilities and fire prevention requirements are represented by the intersection of three multitudes (one of which is sanitary and hygienic requirement).

Certainly, the given graphic model of the structure (see picture 14.1) of functional requirements to the sports and recreation complexes is not the only, and perhaps does not consider some less important requirements, but it is obvious from the model that what a great place take the requirements to the microclimate of the sports facilities in the complex of requirements.

Pic. 13.3 Graphic model of functional requirements to the sports and recreation complex



1. throughput of the complex facilities; 2. filler structures; 3. fire prevention conditions; 4. size of the facility; 5 – the systems of natural lighting and ventilation; 6. placing engineering equipment; 7. aesthetic decoration.

Modern sport is characterized by exclusively high load volume and intensity of trainings. General time spent by sportsmen of high quality is nearly up to 1000 hours per year. Over a long period of dynamic work, energy consumption reaches 500 kcal/hour, and total oxygen consumption comes to 200-500 liters. During high intensive muscular work, the pulmonary ventilation increases up to 100-150 l/min. and frequency of the heart rate is 200-220 beats. Such significant functional shifts during sports activities require ideal environmental conditions in the places intended for physical training. Undoubtedly, the same conditions are required for health and fitness exercises.

One of the main problems of modern sports construction is optimization of microclimate of sports facilities which consists of two interconnected components-scientific substantiation of optimal environment conditions and technical- engineering decisions to provide these conditions.

The second important task is the provision of normative microclimate parameters during designing of sports facilities, which has received little attention up to the present time. According to the data of hygienists engaged in in-situ researches of sports facilities, microclimate conditions during exercises in the indoor sports facilities deteriorate sharply and unfavorable values of microclimate parameters exceed the maximum permissible norms leading to the increase of temperature, air humidity and dustiness. The reasons of these negative phenomena are improper exploitation, architectural planning and construction – technical calculations during sports facilities designing.

At the present time, more than 150 standard designs of sports facilities are used in construction practice. However, the designing features related to the necessity of comfortable microclimate provision in the facilities as well as equipping the facility with heating, ventilation, natural illumination and solar control systems and selection of the facility's orientation according to directions of light were not adequately reflected in them and the relief features of the territory was not taken into account. Design organizations when "binding" model (standard) projects solve the issues concerning planning, orientation and others only from architectural-planning view point without paying due attention to the regulatory issues of microclimate providing for both the facilities and the construction territory. Such kind of solution of the sports cons truction problems is explained by the lack of special methodical developments and documents.

Influence of the external environment on sports facilities is so complex and varied that climatic factors are not considered during their designing and the available scientific data on these issues are poorly used in the practice of sports construction. For example, such kind of climatic factors as insolation of the facility, wind direction and speed are not practically considered during the choice of its optimal orientation and estimation of the heat losses.

The neglect of climatic factors leads to a mismatch calculation and factual condition of the microclimate of sports and recreation complexes and as a result, the conditions of sports and fitness trainings are sharply deteriorated. Thereby, primary attention should be paid to the issues of normative microclimate provision during designing and construction of sports facilities from the earliest stages of design when the contours of future sports facilities are outlined and the principal architectural and planning issues are resolved. Under these conditions, the specialists in construction physics and normative microclimate provision of sports facilities as well as the sports technologist should play the leading roles in the team of designers.

BIBLIOGRAPHY

1. Serebrovsky F.L., *Methods of calculation of the aeration of populated areas*. Hydrometeoizdat publishing, St-Petersburg ,1973.
2. Serebrovsky F.L., *To the issue of aerodynamic similarity*. In book: The issues of town planning and construction physics. Chelyabinsk, Russia, 1972.
3. Designer handbook: *Town planning*. Stroyizdat publishing, Moscow, 1978.
4. Shtenberq A. Y., *Calculation of building insolation*. Budivelnik publishing, Kiev, 1975.
5. Ershov A. V., *Methods of calculation of radiation regime of urban buildings*. Proceedings of Symposium "Construction climatology" , Moscow, 1982.
6. Aysina V. I., *Assessment of the microclimate of building territory in urban design using the equation of heat balance "man-environment*". Proceedings of Symposium "Construction climatology" , Moscow, 1982.
7. Niachou K., Livada I. and Santamouris M., *Experimental study of temperature and airflow distribution inside an urban street canyon during hot summer weather conditions-Part I: Air and surface temperatures*. Building and Environment, 43(2008), pp.1383-1392
8. Mochida A. and Lun I.V. F., *Prediction of wind environment and thermal comfort at pedestrian level in urban area.* Journal of Wind Engineering and Industrial Aerodynamics, 96 (10-11), 2008, pp. 1498-1527.
9. Erell E., Pearlmutter D. and Williamson T., *Urban microclimate*: *Designing the spaces between buildings.* Earthscan, UK, 2011.
10. Moonen P., Defrayeve T., Dorer V., Blocken B. and Carmeliet J., *Urban physics: Effect of the microclimate on comfort, health and energy demand.* Frontiers of Architectural Research, vol.1, № 3 2012, pp.197-228.
11. Allegrini J., Kampf J., Dorer V. and Carmeliet J., *Modeling of the urban microclimate and Its influence on building energy demand of an urban neighbourhood*. CISBAT2013, September 4-6, 2013, Lausanne, Switzerland.
12. ASHRAE fundamentals, ASRAE Inc. Atlanta, 1997.
13. Banhidi L., *Thermal indoor climate*. Stroyizdat publishing, Moscow, 1981.
14. Recommendations on the consideration of climate conditions during architectural – planning solutions of housing. Central SR&DI of buildings, Moscow,1978.
15. Katsnelson Y. I., *Peculiarities of neighborhoods designing under climatic conditions of Turk-menistan*. Hidrometeoizdat publishing, Moscow,1973.
16. Olgyay V. *Design with climate*. Princeton: Princeton University Press, New-Jersey, 1963.
17. Wilmers F., *The small-scale effects of "green" and "shadows" on the urban environment and their bioclimatic importance.* ". Proceedings of Symposium "Construction climatology" , Moscow, 1982.
18. Leontyeva K. S., *Method of complex assessment of the microclimate conditions of the urban territory*. In book: The issues of town planning and construction physics. Chelyabinsk, Russia,1972.
19. Fanger P. O., *Calculation of thermal comfort: Introduction of a basic comfort equation.* AS HRAE Transactions, 73(2), (1967), III4.1-III4.20.

20. SN&R II-3-96. *Building heat engineering*. Stroyizdat publishing, Moscow, 1996.
21. SN&R II-33-75. *Heating, ventilation and air conditioning*. Stroyizdat publishing, Moscow, 1976.
22. Bogoslovsky V. N., *Thermal regime of building*. Stroyizdat publishing, Moscow,1979.
23. Tabunshikov Y. A., *Calculations of temperature regime of premises and the required power for its heating and cooling*. Stroyizdat publishing, Moscow, 1981.
24. Sanchez de la Flor F. and Alvarez Dominguez S., *Modeling microclimate in urban environments and assessing its influence on the performance of surrounding buildings.* Energy and Buildings, 36, 2004, pp. 403-413.
25. Popirin L.S., *Mathematical modeling and optimization of heat power installations.* "Energiya" publishing house, Moscow, 1978.
26. Tabunshikov Y. A., *Basics of mathematical modeling of the building thermal regime as an integrated heat and power system.* Synopsis of thesis for the degree of doctor of technical sciences, Moscow, 1983.
27. Aliyev F.G., *Optimization of energy management in large sport complexes*. Proceedings of the *9th* CIB *Congress*, *Stockholm, 1983.*
28. Bogoslovsky V. N., *Building thermal physics*. "Vischaya shkola" publishing house, Moscow, 1982.
29. Deshko E.L., Turulov V. A. and Khrustov B. V., Proceedings of Symposium "Construction climatology" , Moscow, 1982.
30. Recommendations on the calculation of the heat load on buildings in Central Asia. Tashkent: SR & ED Institute, 1970.
31. Ershov A. V., *Principles of the buildings solar protection in Central Asia*. Stroyizdat publishing, Moscow, 1974.
32. Gulkarov E. S., *The study of heat-protective properties of the windows with sun protecting constructions of civil buildings in summer conditions of Central Asia.* Synopsis of thesis for the degree of candidate of technical sciences (Ph.D), Moscow, 1981.
33. Shvets Y. D., *Methods of calculation of the reflected light entering rooms through the windows with sun blinds*. Synopsis of thesis for the degree of candidate of technical sciences (Ph.D), Moscow, 1973.
34. SN&R 2.01-01-82. *Construction climatology and geophysics.* Stroyizdat publishing, Moscow, 1983.
35. Seppanen O. and Fisk W. J., *Some quantitative relations between indoor environmental quality and work performance or health.* International Journal of HVAC and R Research, vol. 12, №4, 2006, pp. 957-973.
36. Wargocki P., Seppanen O., Andersson J., Boerstra A., Clements-Croome D., Fitzner K. and Hanssen S. O., *Indoor climate and productivity in offices*. REHVA Guidebook, REHVA, 2007.
37. Fanger P.O., *Efficient ventilation for human comfort*. Proceedings of International Symposium on Room Air Convection and Ventilation Effectiveness, Tokyo, 1992, pp. 296-306.
38. Loutzenhiser P., Manz H. and Maxwell G., *Empirical Validations of Shading/ Daylighting. Load Interactions in Building Energy Simulation Tools.* International Energy Agency, 2007.
39. Aliyev F. G., *Microclimate of sport facilities*. Stroyizdat publishing, Moscow, 1983.

40. Likov A. V., Heat and mass exchange. "Energiya" publishing house, Moskow,1972.
41. Berge A. and Johansson P., *Literature review of high performance thermal insulation.* Report in building physics, Chalmers University of Technology press, Sweden, 2012.
42. Chudovsky A.F., *Soil thermal physics*. Nauka publishing, Moscow, 1976.
43. Abramashvili G. G. *Resistant lawns for sports and recreation*. Stroyizdat publishing, Moscow, 1970.
44. Beheizte R., *Sportplàtze* . Sport + Bȁderbauten. №4, 1970.
45. Khromets D.Y., *Thermotechnical bases of designing outdoor sports facilities with an extended operating season*. Synopsis of thesis for the degree of candidate of technical sciences (Ph.D), Moscow, 1980.
46. Aliyev F. G., *Modeling of heat and wind regimes of sports complexes in the hot climate.* Proceedings of "Construction climatology", Part III, Moscow, 1982.
47. Gurevich M. A., *Thermotechnical calculation of sport rinks with overlaid metal elements.* Transactions of SRI Construction Physics: Building heat engineering, issue 19, Moscow, 1978.
48. Lixtenshteyn E. L., *Investigation of the temperature field of artificial ice rink.* Synopsis of thesis for the degree of candidate of technical sciences (Ph.D), Novosibirsk, 1970.
49. Computer program for the calculation of temperature fields of non-uniform enclosing structures under stationary heat transfer. Central SR&DI: Fund of computer algorithms and programs in the field of construction. Engineering and technical section, Moscow, 1975.
50. Recommendations for designing of engineering equipment of artificial ice rinks. SR&DI for Civil Engineering, St-Petersburg, 1972.
51. Bockris O'M., Veziroglu T.N. and Smith D., *Solar hydrogen energy/ The power to save the Earth.* Macdonald Optima, London, 1991.
52. Turkbeyler E., Yao R., and Day T., *Urban microclimate and renewable energy use in cities.* World Renewable Energy Congress, Linköping, Sweden, 2011, pp. 3066-3072.
53. Seynure I., Aliyev F. , Stoller M. and Chianese A., *Optimal configuration of a photocatalytic lab-reactor by using immobilized nanostructured* TiO_2. Chemical Engineering Transactions, 47, 2016, pp. 199-204.
54. Harkness E. and Mekhta M., *Regulation of solar radiation in buildings*. Stroyizdat publishing, Moscow,1984.
55. Sabadi P. R., *Solar house.* Stroyizdat publishing, Moscow,1981.
56. Shafeeva K., *News of helio-technique*. Helio-technique, №1, 1979.
57. Shadiyev O. *Investigation of solar domestic adsorption refrigerator*. Synopsis of thesis for the degree of candidate of technical sciences (Ph.D), Tashkent, 1973.
58. Manic M., Wijayasekara D., Amarasinghe K. and Rodriges-Andina J., *Building energy management systems: the age of intelligent and adaptive buildings.* IEEE Industrial Electronics Magazine ,vol. 10, №1, 2016, pp.25-39.
59. ISO (2014a) ISO 10916:2014 Calculation of the impact of daylight utilization on the net and final energy demand for lighting.
60. AliyevF. G. and Khalilova H. Kh., *The anthropogenic impact on surface water resources in Azerbaijan.* Energy & Environment. vol. 25, № 2, 2014, pp. 343-356.