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ЭНЕРГОСБЕРЕГАЮЩИЕ ТЕХНОЛОГИИ В АПК

ENERGY-SAVING TECHNOLOGIES IN THE AGROINDUSTRIAL COMPLEX

Рекомендовано Учебно-методическим объединением по аграрному техническому образованию в качестве учебно-методического пособия для студентов группы специальностей 74 06 Агроинженерия и специальности 1-74 80 06 Электротехнологии и электрооборудование в сельском хозяйстве

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В учебно-методическом пособии по изучению дисциплин «Энергосберегающие системы в АПК», «Энергосберегающие технологии в АПК» содержатся основные сведения об основных направлениях энергосбережения в сельском хозяйстве, которое рассматривается как одно из главных направлений дальнейшего развития и эффективного функционирования АПК и как самый дешевый источник энергии. Особое внимание уделено технологическим процессам сушки сельскохозяйственной продукции, использованию нетрадиционных и возобновляемых источников энергии; представлены необходимые справочные данные.

Учебно-методическое пособие по дисциплинам «Энергосберегающие системы в АПК» и «Энергосберегающие технологии в АПК» в первую очередь предназначено для студентов очной формы обучения и магистрантов, но может быть полезным для студентов заочной формы обучения агроинженерных специальностей и аспирантов.

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Contents

Preface

It's necessary to advance the specialists' expertise to improve the situation in the area of cost-effective use of resources, that's why the manual considers the issues determining the social objectives' priority directed towards the accelerated achievement of the optimal norms and requirements on power supply capacity and power supply of the agro industrial complex.

The main objective of the manual, taking into account the course program "Energy-saving systems in the agro industrial complex" for technical universities of agro engineering specialties, is to simplify to a certain extent and make a more goal-oriented preparation for practical trainings to improve efficiency of power plants in the agro industrial complex.

The manual is primarily intended for the students of the universities where the issues of a rational use of heat and electric energy in the agro industrial complex are studied and examined. The presented material can be useful for master students, post-graduate students and engineers who specialize in this area.

Some theoretical and practical questions are accompanied by the examples of the calculation methods simplifying their understanding and acquisition. Particular attention is paid to the issues of the received products' preservation, to be more precise, to the drying issues with the usage of modern energy efficient equipment, ensuring a rational use of energy resources.

The author tried to follow the existing programme, to present the material in accordance with the modern trends of the course books.

Introduction

The manual is focused on energy-saving systems in the agro industrial complex, which are technical systems.

System (from ancient Greek. σύστημα – a whole composed of parts; a connection) – a set of elements that are in relationships and connections with each other, which forms a certain integrity, unity [1].

The examples of descriptive definitions [3]:

System – a set of elements that are in particular relations with each other and with the environment.

System – a set of interrelated elements, isolated from the environment and interacting with it as a whole.

The examples of constructive definitions [1]:

System – a combination of interacting elements organized to achieve one or several set goals.

System – a finite set of functional elements and relations between them, separated from the environment in accordance with a specific purpose within a certain time interval.

Accordingly, the main difference of constructive definitions consists in the existing purpose or the system's study from the standpoint of an observer or researcher which is explicitly or implicitly introduced into definition.

Practically every object can be considered as a system. The basic principles of any system:

integrity – a fundamental irreducibility of the system's properties to the sum of the properties of its constituent elements and nonderivability from the ultimate properties of the whole, each element's dependence, the system' properties and relations from its place, functions, etc. within the whole;

structuredness – a possibility to describe the system through its structure establishment, in other words, through communication networks and system's relations, conditionality of the system's behavior from the behavior of its separate elements and its structure properties; the interdependence of the system and environment;

hierarchical pattern – in its turn each component of the system may be considered as a system, and the system represents one of the components of a larger system; description multiplicity – due to each system's complexity its adequate knowledge requires a variety construction of different models each of them describes only a particular aspect of the system.

Systematic approach – the objects' research as systems [2]. It orients research towards the disclosure of the object's integrity and its supporting mechanisms, towards the revelation of the multiple connections' types of a difficult object and bringing them into a single theoretical picture.

Systematic approach is based on the general systems' theory (Ludwig von Bertalanffy) and cybernetics – control theory (Norbert Wiener, W. Ross Ashby, and Stafford Beer). It was formed in the 40–60s of the twentieth century.

Systematic analysis – a scientific method of knowledge, which is a sequence of actions on the structural links' establishment between the variables or elements of the investigating system. It is based on a set of general scientific, experimental, scientific, statistical, mathematical methods.

The value of a systematic approach is that the consideration of the categories of a systematic analysis creates a basis for a logical and consistent approach to a decision making problem. The efficiency of solving problems with the systematic analysis is determined by a structure of the problems to be solved.

Systematic analysis provides the following systematic methods and procedures for the usage in various sciences, systems:

– analysis and synthesis, induction and deduction;
– formalization and specification;
– structuring and restructuring;
– modeling and experiment;
– program control and regulation;
– clustering and classification;
– expert evaluation and testing and other methods and procedures.

The efficiency of the system – a system's property to achieve the desired goal in the specified usage conditions and with a certain quality [3]. The performance indicators characterize the system's adaptability degree to fulfill its set tasks and they are general indicators of an optimal functioning of the information systems. Efficiency is a system's property characterizing its ability to carry out necessary tasks. It's used to compare different systems of the same purpose. Efficiency as a property is inherent only to systems (organizational, technical, biological and so on).

Efficiency is the main indicator of the system's quality performance, characterizing the degree of its ability to fulfill its function as intended (objective fulfillment). It is used to compare the processes of the system itself in order to select the optimal control parameters and also for a comparative evaluation with other systems.

The cardinal general indicators are the system's economic efficiency indicators, determining costs and benefits of the system's creation and functioning.

1. Efficient use of fuel and energy resources

Nowadays the issue of power supply of the agro industrial complex is of great importance because the pace of technological progresses and intensification of agricultural production, technical level upgrading and improvement of working conditions in the agro industrial complex are determined according to the level of its power supply. That's why the main task of the energy development of the agro industrial complex is safe and economic power supply of agricultural consumers, the energy efficiency improvement of production through the introduction of modern technological processes, creation of comfortable social living conditions for the rural population.

The effectiveness analysis of the use of different types of energy shows that recently the growth of agricultural production and improvement of labour productivity have been achieved mainly due to the application of more powerful technology, the growth of fuel consumption, metal and electricity. As a result, the republic consumed in 2–3 times more fuel and energy resources per unit of gross domestic product (GDP) than in economically developed countries with similar climatic conditions and structural economy.

Primarily, distinctive features of energy-saving of fuel and energy resources (FER) in the agro industrial complex are the existence of actual reasons for their inefficient use, which include the following:

– underestimation of energy role and electrification in the development of agricultural production and a social sphere of rural areas;

– capital investments' deficit contributed to the energy sector;

– a low automation level of production processes, which leads to high costs of manual labor in the manufacture of products;

– problem aggravation of technical service, repair and maintenance of power equipment in connection with the collapse of a centralized system of technical support;

– insufficient use of modern technologies, which leads to great losses of energy resources while processing and storing agricultural products;

– insufficient use of local fuels and secondary energy resources;
– non-existence of a scientific support system for the energy-saving developments, the coordinated scientifically aimed programmes, fragmentation of research teams and laboratories, narrowness of their directions. Besides, the innovative industry development is mainly directed towards using foreign advanced technologies and equipment, which limits the development of a scientific and technological progress of a home-grown technology.

A strategic goal of a scientific-technical policy of power industry is to create a sustainable national system of a technical progress development that supports to the necessary extent all production and transport processes and the use of electric energy and heat energy with the high-performance domestic technologies and equipment on the basis of fundamental and applied research results of a national and world science. To achieve the set goals it's necessary to cope with the following tasks:
– priority support of a scientific and technical potential including a fundamental science, the applied research and developments aimed at a continuous improvement and development of efficient technologies and equipment by means of investments to the goal-oriented programmes, modernization of an experimental base, the prototype models' creation and serial production organization;
– development of regulatory legal acts and economic mechanism binding and stimulating the adoption of the prototype models of the new technologies and equipment with their further modification in the actual exploitation conditions;
– creation of a state support system and stimulation of individual enterprises' activities to develop and implement innovative projects;
– use of an international cooperation potential for the application of the best world achievements and an upgrading level of the domestic developments;
– development of technologies, equipment and materials providing the efficiency upgrading in the use of conventional energy resources;
– development of technologies and equipment to use local types of fuel with the technical-economic and also environmental indicators corresponding to the best available test techniques;

– optimization of power supply schemes for specific areas and sites;
– development and implementation of adaptive schemes and intelligence management systems, constructions and equipment for the heating systems and hot water supply of the agro industrial complex and agricultural settlements;
– development of a special system to train and improve professional qualifications of personnel.

The structure of the priority directions of scientific-technological activities in the Republic of Belarus for 2011-2015 [15] is examined according to the key directions that have been highlighted in the so-called critical technologies:

1. "Agricultural raw materials' processing":
– cereal grains' processing including the production of food alcohol, flour for confectionery products, and brewing malts;
– processing of sugar beet and cane sugar, including the white sugar production;
– oilseeds' processing, including the production of rapeseed oil, fat and margarine production;
– processing of fruits and vegetables, including the production of the canned fruits and vegetables, childhood nutrition, juice, wine;
– manufacture of packaging and containers [1];
– advanced processing of livestock and plant production, storage adaptive systems;
– non-waste processing of by-products and joint-cost goods of meat, dairy, alcohol, beer, malt, fish and other food industries;
– drying of plant raw materials and semi-finished products, a vacuum freeze of semi-finished and finished products, disinfection of equipment, raw materials and finished products; the systems of a membrane treatment of industrial and sewage waters.

2. "Manufacture of livestock products, breeding and protection of agricultural animals"
– manufacture of livestock products (meat and milk production) on the basis of the high-intensity economic management's methods;
– fodder conservation;

[1] *It influences efficient energy use while organizing the products' storage.*

– improvement of methods and systems of the farm animals' protection (sanitation of air in rooms).

3. "Systems and complexes of the agricultural machinery and equipment"
– development of the automated and robotic control systems of technological processes of the agricultural machines;
– creation of resource-saving complexes of machines and equipment for melioration, animal husbandry, livestock products' transportation;
– development of new generation machines for a post-harvest products' handling, a dispatch for storage, finished products' processing and production.

Nowadays the energy development of the agro industrial complex occupies the second stage, which involves an intensive development path with the use of highly efficient energy-saving technologies of the coming generation. That's why the efforts in this area will be focused on the formation of highly profitable and sustainable agricultural products and agricultural production processing with a high level of mechanization and automation that must be relevant to the world standards. Therefore, the main task is to complete modernization of agricultural production in order to make it profitable by 2015.

The main scientific directions of the energy efficiency improvement of the agro industrial complex of the Republic of Belarus are shown in Table 1.1. Let's carry out an analysis of them.

The final energy reduction involves: firstly, reduction of materials consumption of the national income, in other words, if technologies employed in industries are aimed at using a less amount of the raw material, than its processing costs will be reduced. Secondly, energy-saving technologies will reduce energy costs having a fixed amount of products manufactured by an enterprise. Thirdly, it means a consolidation of single capacities and exploitation of combination installations.

For example, a condensation power station (CPS) with unit capacity of a power-generating unit 300 MW to produce 1kWh consumes 263 grams of coal equivalent, and CPS with unit capacity of 200 MW – 278 grams of coal equivalent.

Combined heat and power plants (CHP), producing electricity and heat energy simultaneously, are an example of cogeneration.

Table 1.1. Main energy-saving directions

1. Final energy reduction	2. An increase of the FER utilization coefficient	3. Substitution with other energy resources
Energy-saving technologies	Dismantling, reconstruction and modernization	Electrification on the basis of alternative and renewable energy sources
A rational choice of raw materials and energy carriers	Improvement of power engineering equipment	Electrification on the basis of cheap coal
Progressive technological processes	Optimization of technological processes	Electrification on the basis of nuclear fuel
Improvement of production control	Utilization of secondary energy resources	
Reduction of materials consumption of gross domestic product (GDP)		
	Strengthening of unit capacities	Exploitation of cogeneration plants

The utilization coefficient increase of energy resources involves the following:

– reconstruction and modernization of enterprises;

– improvement of power engineering equipment;

– secondary resources' utilization (flue gases of boilers, furnaces, reduced steam).

The main directions of the efficient energy use are connected with the utilization coefficient increase of energy resources.

The quality of the source raw material and energy resources is due to the improvement of raw material components (cleaning, drying), its physical state (grinding, pelletizing, briquetting) and a chemical constitution (calcination, plasticizers' addition), although it all require additional energy costs and other resources, but as a rule, give a positive total effect.

In terms of energy resources, it's important to concentrate on the quality improvement of supply electrical voltage, the preheating of liquid fuels of heavy fractions (heating oil), and natural gas purification from impurities. All these lead to a more efficient use of energy resources and raw materials, and the operational characteristics' improvement of the processing plants.

Maintenance and repair of the processing equipment involve maintaining of technical devices under regulatory operating conditions, which makes it possible to withstand the performance standards concerning the consumption of energy resources and elimination of overheads.

The main activities include: a light fitting and a workshop glass fixing; adjustment of burner devices, hydraulic regimes of heating networks; elimination of heat-insulation defects, leakage of water, steam, compressed air; repair and replacement of worn-out parts and components.

Rationalization of the equipment's operational regimes can be attributed to the following. The energy consumption for the operation of practically any device has two components – constant or cold run, being independent of the device's loading and connected with the transfer from inoperable condition to operational, as well as the variable increasing with the growth of the load. Minimum energy consumption corresponds to the nominal load or nominal operational regime that is close to the maximum. Thus, in a nominal operational regime losses (idling energy consumption) account for 10–30 %; while reducing the load by half the proportion of the unproductive energy costs increases by 18–46 %.

The use of secondary energy resources (SER) in technological processes of the agroindustrial complex has a perspective. Secondary energy resources (SER) of high-temperature technologies (400–1000 ^{o}C) that are related to heating, melting, sintering, heat treatment or sublimation have the greatest potential. The losses' magnitude with flue gases can reach 70 %. A significant disadvantage of the utilization of secondary energy resources (SER) is their inconstancy as a source and high equipment expenses for their production. An essential part of the non-used SER belongs to the so-called low-potential secondary energy resources (SER), these are steam (pressure1–5 ga); flue gases (100–150 ^{o}C); cooling water with temperature fluctuation for 5–10 ^{o}C, ventilation exhausts.

Modernization and reconstruction are the most efficient and expensive energy saving directions with the help of which the equipment has to be replaced or significantly improved, technological processes are reorganized. The most common types of the activities are the following:

– adoption of the frequency regulation systems of the electric drive to reduce energy consumption costs;

– replacement of piston compressors with screw compressors to reduce energy costs to produce compressed gas;

– old-fashioned ventilators' replacement with new ventilators and adoption of the automatic control systems to reduce energy consumption costs for ventilation;

– replacement of light bulbs with more economical types of light sources to reduce energy consumption for lighting;

– adoption of the advanced production technologies.

The utilization coefficient increase of energy resources in plants can be achieved due to:

– improvement of a technical level and efficiency coefficient of thermal generation plants, improvement of their designs;

– reduction of losses in heating and electric networks;

– use of low-potential heat via heat pumps, heat recovery of ventilation exhausts on farms;

– decentralized consumers (biogas, solar, wind, geothermal, hydropower resources);

– use of SER (for example, the diverting and waste heat of enterprises);

– usage regimes' rationalization and adoption of a science-based power rationing.

While planning electricity that uses alternative and renewable energy resources (ARES) it's essential to take into account their distinctive features in comparison with conventional energy resources. The following features are referred to them:

– an action frequency depending on nature phenomena that cannot be controlled by man, and as a result, power fluctuations of renewable sources from extremely irregular sources like the wind;

– low densities of energy fluxes and their distractibility in space is significantly lower than of steam boilers, nuclear reactors).

The economic efficiency of the use of any renewable energy resource should be determined according to natural conditions and geographic characteristics of a particular region. The use of renewable resources is effective on the condition that an integrated approach is applied.

The main alternative and renewable energy resources of the Republic of Belarus are hydropower, wind power resources, solar energy, biomass and municipal solid waste.

Regarding the use of nuclear fuels, the Government of Belarus has approved the project documentation of the Belarusian nuclear power plant (NPP). This decision can be found in the resolution of the Council of Ministers №857 from September 30, 2013. According to the document, technical and economic indicators of the capital construction project “Belarusian NPP” (Figure 1.2 and 1.3) are as follows: 2 power-generating units with installed rated capacity of 1194 MW each, installed capacity of the plant is 2388 MW. The nuclear power plant’s operating term is 50 years, with an average annual electricity generation if the nuclear power plan operates with a basic regime – 17 095,1 kWh.

Figure 1.2. The project of the Belarusian nuclear power plant

а *б*

Figure 1.3. The first Belarusian nuclear power plant:
a – the NPP construction site; b – the plant's location

2. Energy-saving technologies of the agricultural products' drying

A heat (thermal) drying is a heat-consuming technological process in consequence of which consumable goods or/and intermediate products are obtained.

According to the data of the Economic Commission for Europe, the average efficiency coefficient of the drying installations (DI) is only about 30 ... 33 %. The efficiency coefficient increase of DI would double the annual savings approximately to 60 million tons of coal equivalent; it means about 30 % of the planned amount of the whole country's savings.

The main directions of the DI improvement indicators are:

– heat utilization of the spent drying agent;
– improvement of the DI heat insulation and hermetization;
– creation of compact designs;
– improvement and automation of furnace installations;
– application of modern control and regulation methods of the drying process.

The reserves' identification of efficient energy use has a number of aspects:

– *methodological* (for example, development of the universal cross-industry methodology of the reserve's identification of energy-saving;
– *technical* (for example, use of SER, reduction of heat losses with the DI insulation;

– *social-economic* (for example, reserve's search stimulation of energy-saving;

– *organizational* (for example, coordination of activities concerning energy-saving);

– *environmental*.

Energy balances are effectively used to assess energy efficiency of the separate drying installations, as well as to solve the questions of the activity's analysis of enterprises' subdivisions at which they are widely used.

Thanks to the balance it is possible to assess quantitively the energy share spent efficiently and its losses, the efficiency coefficient and other profitability indices of the drying installations. It should be pointed out that the losses of the drying installations have a crucial meaning.

Energy losses in the systems can be classified:

1. According to the possibility and reasonability of their elimination:

– total losses;

– inherent losses determined with technology peculiarities and equipment;

– losses that technically can be eliminated;

– losses the elimination of which at the present conditions is economically feasible.

2. According to the place of their occurrence:

– in storage;

– during transportation;

– during processing;

– during the usage of heat carriers (heat-transfer agents).

3. According to physical properties and character:

– heat losses to the environment with the exhaust gases;

– with technological production or wastes because of material;

– energy losses in transformers, electrical transmission lines;

– hydraulic pressure losses and mechanical frictions.

4. According to the reasons for losses' occurrence:

– because of structural defects;

– because of a wrong selection of a technological processing regime;
– because of the equipment misuse;
– because of a low repair quality.

Currently, the national economy of the Republic of Belarus exploits a great amount of the drying installations with the efficiency coefficient varying from 12 to 80 %. Convection driers used as the drying air agent, inert or flue gases, with an average range of the efficiency coefficient varying from 12 to 60 %, have become the most widely used (up to 95 % of the whole park of the drying installations).

According to the average statistical data on heat balances of the continuously operating convection drying installations, heat input is consumed approximately for:
– moisture evaporation – 20–60 %;
– material heating – 5–25 %;
– heat losses with the outgoing drying agent – 15–40 %;
– heat losses due to the wallings – 3–10 %;
– other losses – 5–20 %.

The last article on energy expenditure goes up to 30–35 % for batch dryers. Only heat input for moisture evaporation is referred to the usefully used energy costs.

The energy profitability index of the drying installations with a convection method of heat supply has particular characteristics. The efficiency coefficient of the convection driers is equal to:

$$\eta(t) = \frac{t_1 - t_2}{t_1 - t_0} ,$$

where t_1 – the temperature of the drying agent at the inlet to the dryer, °C;
t_2 – the temperature of the drying agent at the outlet from the dryer, °C;
t_0 – the air temperature of the environmentте, °C.

The analysis of this formula shows that the efficiency coefficient of a convection drier may vary from 0 to ∞: when $t_2 \rightarrow t_1$ it is equal to $\eta(t) = 0$, and when $t_1 \rightarrow t_0$ it's equal to $\eta(t) = \infty$. Because the temperature of t_2 tends to tw (the temperature of a wet thermometer), after the difference of $\Delta t = t_1 - t_2$ will be more than zero. Relying on everything mentioned above it's possible to conclude that there exists a maximum efficiency coefficient of a convection drier that is determined with the dependency:

$$\eta(t)_{\max} = \frac{t_1 - t_w}{t_1 - t_0},$$

where t_w – the temperature of a wet thermometer, corresponding to the terminal parameters of the drying agent, °C.

The behaviour of the maximum efficiency coefficient from the initial temperature of the drying agent, (having different temperatures and moisture content of the environment), is shown in Figure 2.1, for the most simple case of its single use.

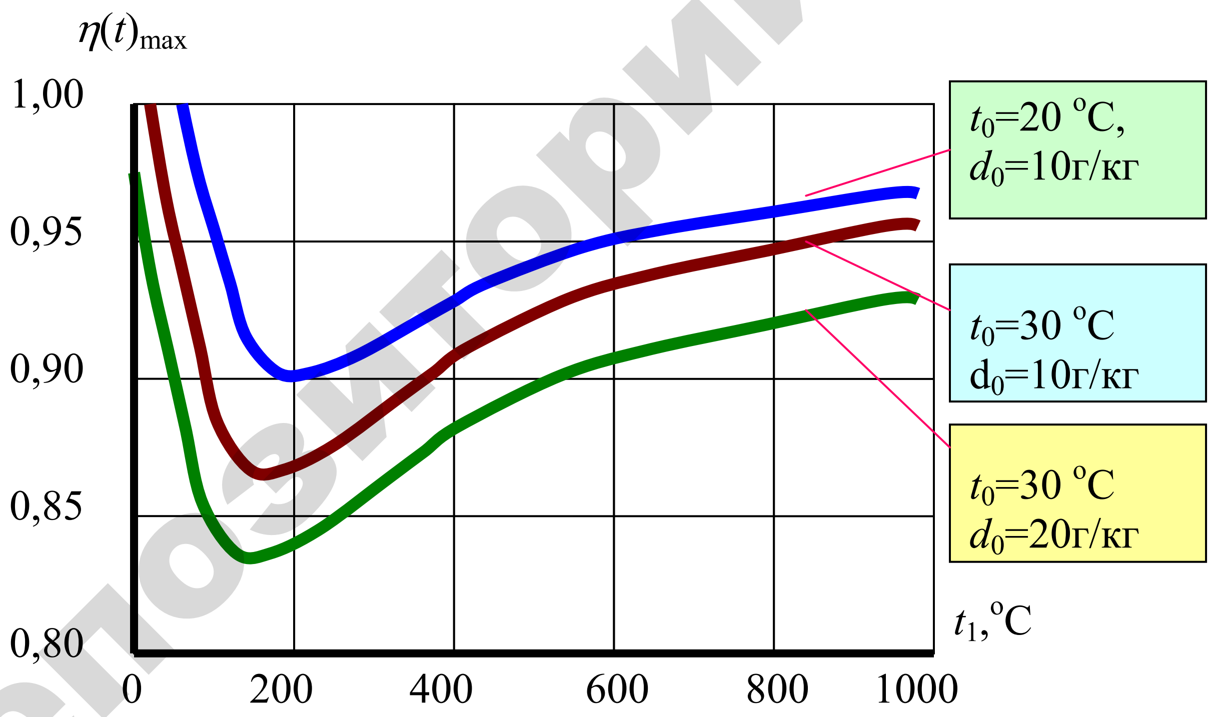


Figure 2.1. Behaviour of the maximum efficiency coefficient for a single use of the drying agent

In a general case the ultimate efficiency coefficient of the convection driers depends on:

– initial and final temperature of the drying agent;

– temperature and moisture content of the environment;

– correlation of the sums of specific heat inflows and heat losses ($\Delta = qhi - qhl$);

– a heat grid of the drying installations (the number of zones of the intermediate heating, recirculation, etc.).

A specific energy consumption per 1 kg of the evaporated moisture is a sufficiently objective and conservative characteristic of the DI energy efficiency. As it's known, under normal conditions, a theoretically required amount of heat for evaporation of 1 kg moisture is 2200–2700 kJ/kg. The upper limit of the specific heat consumption is referred to the case of the bound moisture elimination. For example, this quantity is 3000–4000 kJ/kg in the wood-drying kilns of a continuous operation with a counter-flow circulation of the drying agent, and in the compartment kilns it is 2700–6500 kJ/kg. When drying thin and flexible materials such as paper or fabric, it's 5000–8000 kJ/kg. Industrial convection dryers for the pasty materials' drying have even a greater specific consumption.

Taking into consideration everything stated above, it's possible to propose the following classification of the methods to increase the convection dryers' heat efficiency.

1. Heat engineering concerning the drying installations in general:

a) heat engineering (a selection of a heat grid, the dryer's regime parameters, the operating regimes of an installation, recirculation ratios, the control of the final moisture content of the drying agent, etc.);

b) constructional and technological (optimization of the intermediate heating zones, a selection of directions of the drying agent's and material's reciprocal motion, improvement of the heat supply system and aerodynamic conditions in the dryer, etc.).

2. Kinetic facilitating of the dryer's efficiency improvement and thereby affecting the installation's dimensions and its efficiency coefficient.

a) intensification methods of the external heat-mass-exchange (an increase of a temperature pressure drop, a driving force of mass exchange, the heat transfer coefficient to the drying material, the heat exchange surface, etc.);

b) intensification methods of the internal heat-mass-exchange (material temperature increase, especially in the initial stage of the drying, the decrease of the thermal-diffusion constituent of a mass flow with its multidirectionality with the diffusion constituent, use of the external fields – electric, magnetic, acoustic, use of surface-activated substances, oscillating modes of heat supply).

The heat and mass transfer has a decisive influence on the drying speed, on the product's quality and energy consumption.

The intensity of the internal transfer is primarily determined by the moisture content differences, temperature, and (sometimes) by pressure in the volume of material, as well as, by the value of the moisture diffusion ratio and value of the thermal moisture conduction ratio. The transfer of moisture in the form of liquid takes place in the direction of the moisture content reduction, temperature and pressure, and is inseparably linked with a heat transfer.

The internal transfer intensification is carried out due to:

– alteration, if technology allows, of the material structure before or after the drying in order to increase heat and mass conductivity;

– introduction of small additives to the material capacity size, for example, surface-activated substances, that may also have an accelerating effect on the internal transfer;

– control of the temperature distribution pattern, moisture content and pressure in the capacity size of the material, using various and frequently changing through time means and parameters of the electric conductor to the material.

The intensity of the external heat and mass exchange (sometimes called evaporation) increases in a direct correlation from temperature drops and concentration of an evaporating substance from the material in the environment and at the surface of the material.

Intensification of external heat and mass transfer is made with:

– an increase of the temperature drop and concentration of the evaporating substance in the environment and at the surface of the material;

– an increase of a motion speed and turbulence degree of the environment, with a change of a motion's direction;

– alteration of the environmental properties, for instance, the usage of inert gases instead of air, inert fluid means to the moisture, while exercising a process in a rarefied environment or at elevated pressure;

– usage of electromagnetic radiations (infrared, high-frequency range), leading to a sharp increase of the energy flow supplied to the material.

The combined intensification methods of the drying are the most effective in the majority of cases. The energy efficiency is performed as a result of intensification, primarily due to:

– reduction of the overall processing time and correspondingly due to the decrease in energy losses;

– energy supply localization and reduction of its inefficient consumption;

– reduction of the drying agent's consumption and correspondingly its transfer energy.

Material transfer while drying; the direction of a periodical change of a drying agent's motion concerning the material; the use of high-temperature and oscillatory modes (while alternating the heating and cooling) can be referred to the exercised in practice methods used for intensification of the heat and mass transfer.

While drying energy efficiency is inseparably connected with a technological task that's to obtain the dried materials of the required quality. The overriding importance belongs to the power supply method (convective, conductive, thermo radiation and etc.) as well as, to parameters of a dryer's mode; for example, when a convective method of power supply is used, than the drying agent's temperature, humidity and speed are of a great significance.

It's evident from the heat balance of drying installations that from the energy-saving perspective it's obligatory to finish the drying with a maximum moisture content of the material permitted according to technological restrictions. The overdrying leads to the additional energy costs for moisture evaporation and overheating of the material. The product quality control is an essential element of the general energy-saving task, because the derivation from the required parameters leads to a necessity of a product's processing or other activities linked to the energy consumption. To implement an integrated approach for the creation of various drying installations it's necessary to develop the automatic regulation systems, which ensure the significant energy efficiency.

From the analysis of the heat balances of the convection driers it follows that the biggest heat losses are caused by the outgoing drying agent and heat losses to the environment. Obviously, a rational heat use of the outgoing drying agent in different types of the utilizing installations is not a perspective direction of the fuel and energy economy in the convection drying installations, but the universal reduction of these losses. The last-mentioned is primarily achieved due to recirculation of the spent agent that reduces the outgoing drying agent's costs in dozens of times.

There are two possibilities of recirculation organization in installations that use air as the drying agent:

– a part of the spent air is returned to the zone in front of the heater so that the whole drying agent (fresh and spent air) is heated to the temperature at the inlet to the dryer;
– a part of the spent air given to the zone after the heater is mixed with the heated fresh air and further is given directly to the dryer.

The moisture content increase and temperature reduction of the outgoing drying agent from the dryer lead to the gain in the heat efficiency of the installation. However, the implementation of a stated technological method can also have negative consequences. Firstly, the moisture content increase and temperature reduction of the drying agent at the inlet from the dryer can in some cases lead to a spontaneous phenomenon of a homogeneous moisture condensation when the outgoing drying agent mixes up with fresh air. Secondly, the moisture content increase d_2 at a temperature $t_2 = \text{const}$ of the drying agent at the inlet from the dryer leads to a lowering of a driving force of the external mass transfer and correspondingly to a lowering of evaporation intensity, as well as, to the alteration of the heat-exchange coefficient due to the changes of the drying agent's physical characteristics.

There is a marginal coefficient of recirculation that provides with the preselected t_1 and t_2 the heat minimum specific consumption in the drying installation which can be defined as:

$$Kp_{\max} = \frac{h_2 - \Delta}{C(t_1 - t_2)},$$

where h_2 – steam enthalpy at a temperature of the drying agent at the inlet from the dryer (t_2), kJ/kg;

C – specific steam heat, kJ/(kg·K).

The actual recirculation coefficient can be selected in the range from 0 to $Kp_{\max}$. It should be remembered that the closer the recirculation coefficient approaches the maximum value, the closer the efficiency coefficient of the drying installations to (100 %).

The recirculation coefficient may vary in a drying process. At the beginning of the drying, when the temperature of the outgoing air from a chamber is minimal, and the moisture content is high, the recirculation coefficient should be minimal. Further, it can be increased. In winter, when the moisture content of the outside air is small, the operation with a high value of the recirculation coefficient is possible. Accordingly, when the moisture content of the environment is high (in summer), the recirculation operation of the drying agent may be unreasonable.

While undertaking an experimental study of the convection drier for the drying of potatoes, grain, and other agricultural products with the part of the spent agent's recirculation (Figure 2.2), the following results are obtained. While drying potatoes with recirculation of 46 % of the spent drying agent, the specific heat consumption is 3450 kJ/kg, and without recirculation it is 3850 kJ/kg. In this case the heating oil's saving is about 10 %. Some data of the carried out experiments are presented in Table 2.1.

To improve the efficiency of the heat recovery systems in the drying installations, it is perspective to use heat pumps – heat converters, which increase the heat carrier's temperature at the expense of doing work.

There are three types of heat pumps: compressive, sorption (absorption) and thermoelectric.

Table 2.1. Specific energy consumption for the drying, kWh

Drying material	With recirculation	Without recirculation
Food grains	17,0	17,2
Potatoes	20,2	20,8

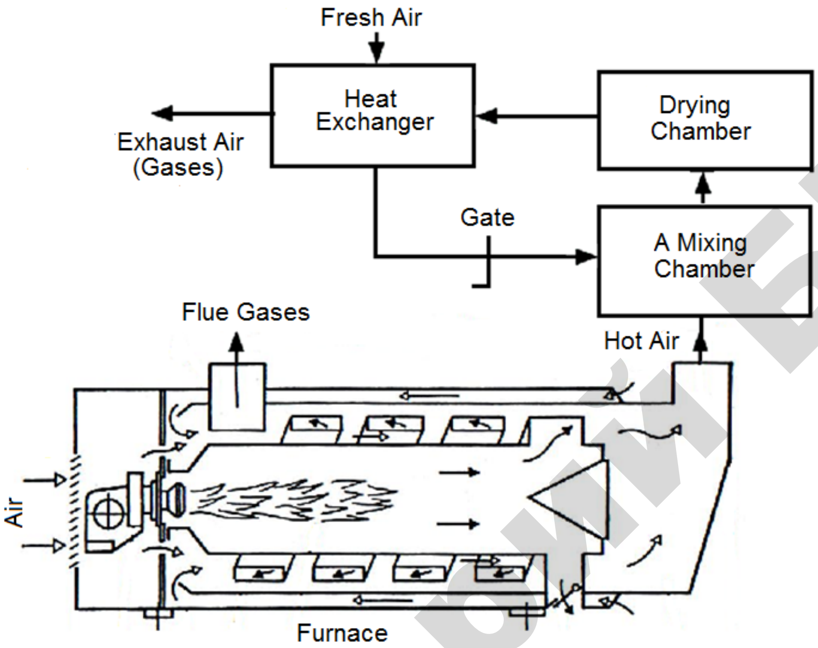


Figure 2.2. Design of the heat-exchanger's usage for heat recovery in the drying installation

While drying grain, clothing and wood the usage of the spent drying agent's heat by means of a heat pump reduces the energy consumption approximately by 50–80 %, but the drying installation must operate no less than 200 hours per year, otherwise it can be inefficient.

Let's examine the typical designs of recuperators' and heat pumps' application in the drying installation while drying various materials. The simplest utilization installation is a heat-exchanger and recuperator, where the incoming air is heated with a flow of the outgoing air (Figure 2.2 and 2.3).

The outgoing air penetrates into the evaporator of the heat pump (Figure 2.4), where it gives the heat to a boiling working fluid. The steams of the last mentioned are pressed together in the compressor and penetrate into the condenser. While condensing the steams heat up the incoming atmospheric air in the dryer. The design is very popular and is used for the grain drying in the USA.

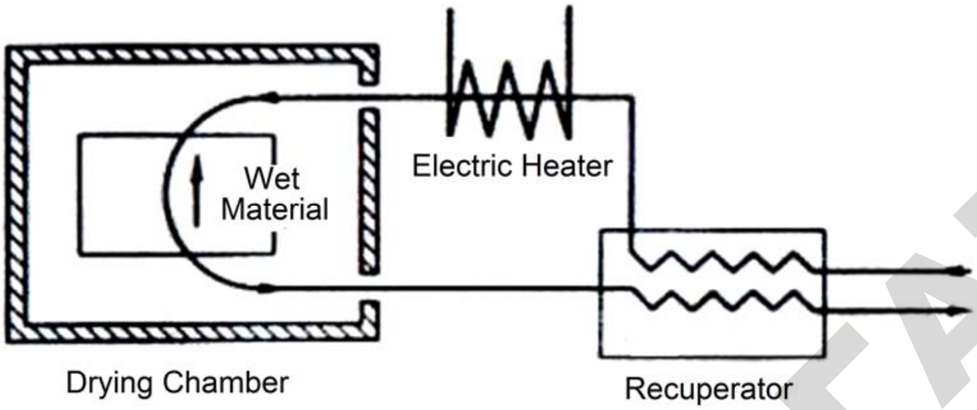


Figure 2.3. The drying installation's basic design with heat recovery of the outgoing air

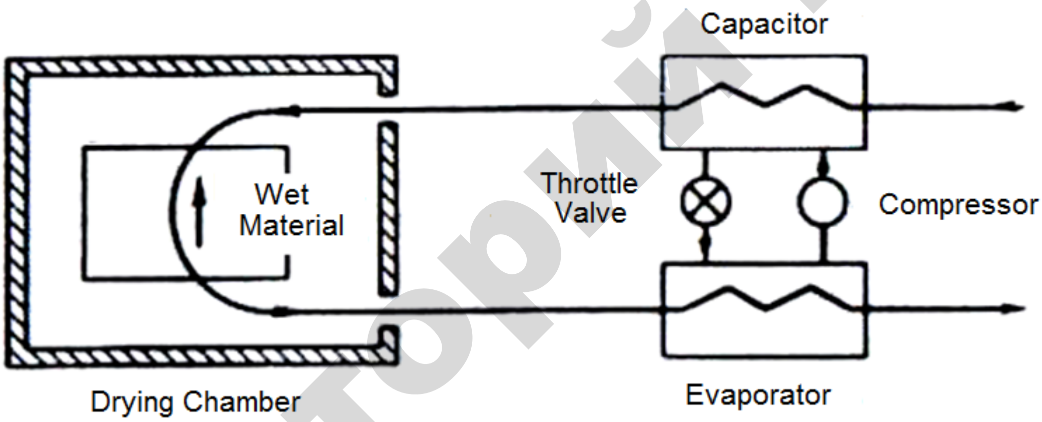


Figure 2.4. The drying installation's basic design with the heat pump usage

The design of the drying installation (Figure 2.5) operates by analogy with the previous design (Figure 2.4). On condition it's not possible to heat the air in the condenser to the required temperature, than an electric heater must be additionally installed.

The drying installations' designs with the application of a heat pump dryer have become widely spread abroad. The design with a heat pump dryer (Figure 2.6) allows a closed air circuit. In the evaporator the wet air cools down below a dew point (drained) and penetrates into the heat pump condenser, where it is heated to the required temperature. To reduce the heat quantity, necessary for heating, a channeling effect of the air part, avoiding the evaporator, is used, which increases its temperature before the condenser.

Regarding the use of electric energy in the drying installations it's essential to point out that while drying its usage is interconnected not only with a necessity of providing electric motors with the drives of ventilators and pumps, but also with the use of electric calorifiers as supplementary heaters.

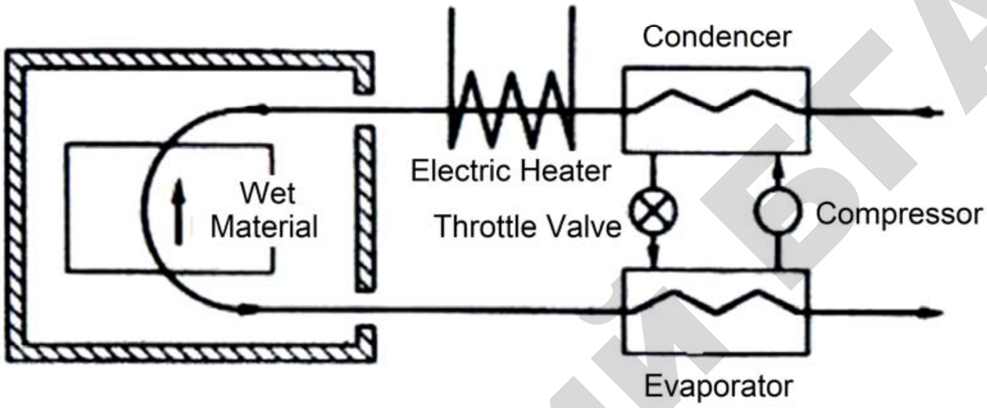


Figure 2.5. The drying installation's basic design with the heat pump and the heater

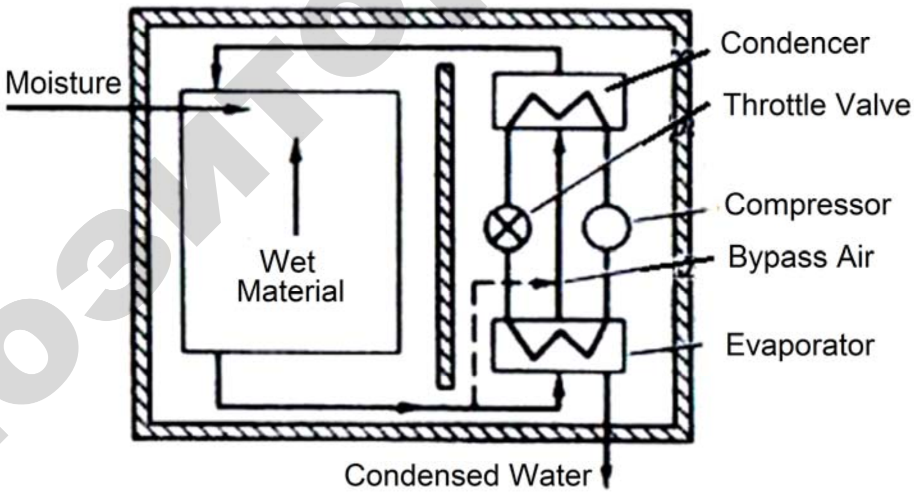


Figure 2.6. The drying installation's basic design with the usage of the heat pump dryer

At large enterprises which consume a lot of energy and equipped with the drying installations (for example, baked goods' factories), a rational energy use is ensured with:

– a maximum use of energy during off-peak periods of the load curve (as a rule at nights);
– condensing units' usage or modern universal controllers ComEC и SinuMEC to improve the energy quality (harmonics' elimination and a sharp decrease of nonlinear-distortions' coefficient) and a decrease of a reactive power for inductive loads, lead to the capacity coefficient increase;
– use of high-effective pumps, ventilators and electric motors of the new generation.

The DI electrification feasibility may be determined according to a limiting value of electrification costs. In many practical important cases an electrification variant, when adducing to comparable conditions, is more efficient regarding sanitation and product quality.

There are two approaches on how to solve large-scale problems related to the environment protection (ecological problems):
– installation of a special equipment for purification of all kinds of waste products, meanwhile, the wastes quantity is the same;
– development of no-waste and energy-saving technologies by means of a change of the main and drying equipment, taking into account a necessity to reduce the wastes quantity, and sometimes their alteration into amenable recycling forms (for instance, for burning to generate the heat energy), etc.

The analysis of foreign literature sources shows that research and engineering works to improve technologies and technical means of the grain drying are aimed at reducing the energy consumption, materials and labour costs.

Companies of such countries as the USA, France, Germany, Great Britain, Sweden, and of other countries produce the installations to dry grain in a various constructive design, and it allows meeting the needs of agriculture to the fullest extent possible.

With all structural varieties it is possible to reveal general tendencies for the development of technologies abroad:
1. Convection drying installations for grain drying of a batch and a continuous operation have become widely spread.

2. Grain drying technology, on the place of its storage with the outside air or the slightly heated up air (a low-temperature drying), is spread. Ventilated metal barns, bunkers of the active ventilation, warehouses-dryers are used for this purpose.
3. On farms the various dryers in design of a batch operation (mostly mobile) are used.
4. A number of innovative technical and technological solutions have been implemented in the construction dryers of a continuous operation.

These technology solutions include:

– a modular principle of the grain dryers' layout of various capacity;
– a technological process of intensification at the expense of the use of heat-differential and aerodynamic regimes, the preheated air;
– an application of cyclones, filters, dust collectors and special ventilators to purify the used heat carrier from dust and impurities;
– automation of a technological process with computers;
– dryers' open design (no buildings) made of the prefabricated units of a full operational readiness;
– use of corrosion-resistant and insulating materials in the design;
– creation of a high operational reliability of the main and auxiliary units of dryers (chain bucket elevators, ventilators, furnace installations, automation).

The methods used abroad and directed towards reducing the consumption of liquid fuels while drying grain deserve a lot of attention.

– use of furnace installations that operate on natural and condensed gas, solid fuel (from plant residues and wastes);
– the spent heat carrier's recirculation, including its intermediate heating;
– reliable heat insulation of the heated dryers' surfaces;
– use of a two-stage heating dryer and grain cooling.

Foreign drying technologies used on farms have a high performance, the efficiency coefficient is 70–75 %, the opportunity to use alternative energy resources; moreover, they are equipped with the automatic-control systems of the electrical drive and separate units, control of their operation, technological adjustment parameters of a drying process. Recently, the automatic-control systems have been developed with the drying installations and aggregates on the basis of compute engineering (for example, a ventilating-drying computerized aggregate "Zeelov1" produced by the company GEHALA for grain drying on granaries, Table 2.2).

Table 2.2. Technical characteristics of a ventilating aggregate

Characteristic	Value
Maximum height of a dump for grain, m	4,5
Maximum height of a dump for rapeseeds, m	2,0
Maximum initial grain moisture (wheat, corn, barley), %	22
Maximum initial grain moisture (rapeseeds), %	15
Maximum relative moisture of the given air (no more), %	90
Maximum capacity of a dryer (wheat, corn, barley), m^3	2300
Maximum capacity of a dryer (rapeseeds), m^3	1500
Capacity of a ventilator's drive, kW	18,5
A rotation frequency of an electric motor, min^{-1}	1450
Ventilator's performance, m^3/hr	27000
Capacity of an electrical heater, kW	50

In our Republic polish mines of the drying installations M819 had been exploited for a long time (and are being exploited), they have been improved to increase their effectiveness. After the reconstruction of such drying installations a cooling chamber has been turned into a heating chamber. Besides, an additional dry grain hopper with a cooling chamber has been installed.

Currently, the radiation (thermo radiation) drying installations of moist materials are being widely used; their action principle is the infrared radiations' usage, (IR, the wavelength range from 0,8 microns to 0,8 mm). When the radiation heating is in a process, the heating of the material and moisture evaporation from it occurs as a result of the absorption of radiant energy emitted by a high-temperature source. The penetration of radiant energy into the depth of the material (a capillary-porous body) facilitates a more uniform heating of it through thickness, thus increasing the intensity of heat and mass exchange. While using a radiation drying, the heat flow's capacity is in 30–70 times more than convection [32].

Long-waves (> 4 pm) and gas (no-flaming) burners or electric IR with a shell made of porous ceramic or silica refractories with the temperature of an emitting surface of 300–800 °C, as well as panels heated with high-temperature combustion products are used as IR sources (Figure 2.7). IR medium-waves (2–4 microns) with bodies of heat from wolframite or nichrome are usually tubular in a shell from quartz glass having a temperature of 900–1200 °C. Short-wave radiators (0,8–2 mm) are made in the form of quartz halogen lamps with a temperature of 2200 °C or higher.

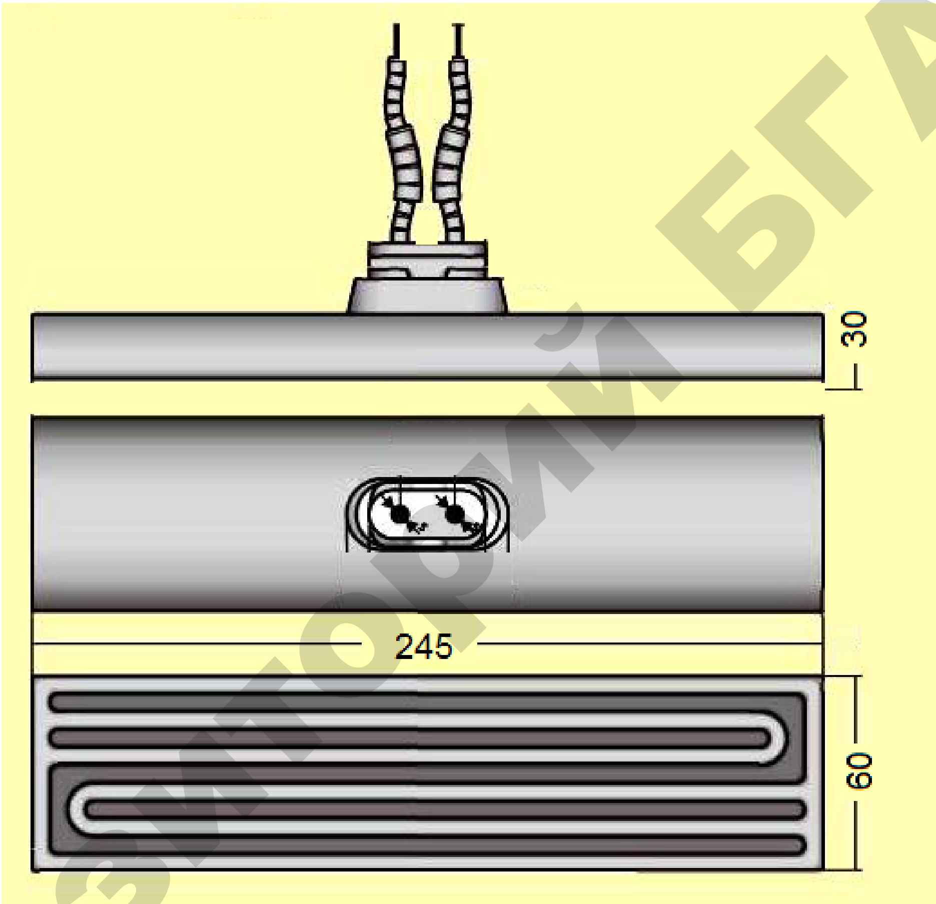


Figure 2.7. Ceramics IR of the panel type

An infrared drying method has significant advantages over a traditional, convection method. First of all, it is an economical effect. The consumed energy and speed in the infrared drying are significantly less than the same expended indices with traditional methods. Food products' sterilization is also a positive side effect.

Thanks to an infrared drying it's possible to solve current problems of many industries – to dry grain and timber, brick and raw cotton, medicinal herbs. Equipment to dry fruits and vegetables, meat and fish, grain, cereals and other food and non-food materials, based on the use of the infrared radiation, is the most promising in current times. Products, dried in a similar way, have a longer date of expiry without changing their qualitative characteristics.

An infrared timber drying lasts approximately 3,5 hours, from which the active working time of the infrared radiators is 2 hours. The drying time of cuttings is 30 minutes. Short-wave infrared rays have a greater impact on food products, both due to a great depth of penetration and a more effective influence on the molecular structure of food products.

An infrared drying of food products, like a technological process, is based on the fact that infrared radiation is actively absorbed with water contained in a product, but the cloth of a drying product is not absorbed. Therefore, the removal of moisture is possible at a low temperature (40–60 °C), and thanks to it, it's practically feasible to preserve vitamins, biologically active substances, natural color, flavor and aroma that are exposed to the drying of products. An infrared drying manufactures products that do not contain preservatives and other foreign substances, and these products are not exposed to the influence of harmful electromagnetic fields and radiation. Infrared radiation is harmless to the environment and humans, as well as its using equipment to dry fruits, vegetables, meat, fish, grains, cereals, etc. The dried product is not critical to the storage conditions and is resistant to the microflora development.

The products' drying has two advantages: firstly, at such temperatures a product is maximally preserved: cells aren't torn, vitamins are conserved, and sugar doesn't become caramelized; secondly, low temperatures don't make warm the drying equipment, it means that there are no heat losses through the walls, ventilation. At the same time at a temperature of 40–60 °C infrared radiation destroys all microflora at the product's surface, making the dried product virtually sterile.

At present the very interesting developments to increase the drying installation's effectiveness also exist in the sphere of super-high frequencies (SHF) of grain material. The SHF drying is based on the fact that dielectric properties of water and dry substances of food products are different: moist material is heated much faster than dry material.

Specific heat flux (W/m^3), producing during the SHF drying can be determined:

$$Q = 0{,}555 f \cdot \mathrm{tg}\delta \cdot \varepsilon \cdot E^2 ,$$

where E – electric field's density, V/m;

f – electric field's frequency, Hz;

ε – material's relative dielectric permeability;

tgδ – angle's tangent of dielectric material losses.

The lower ε, the greater depth of electromagnetic fluctuation's penetration into the material. With the growth of tgδ the heat generation increases while the material is being processed.

The SHF grain dryer (Figure 2.8) is designed to remove moisture from granular materials by means of microwave drying, and is used to obtain the desired moisture content of grain seeds and oil crops including seed stock, also it produces disinfection, decontamination of the dried product from harmful bacteria, fungi, including mould.

The installation allows operating in several drying regimes, which can both suppress and stimulate seeds' viability. While treating the seed stock, a special sparing regime of treatment, which doesn't destroy a living component of seeds, is used.

The use of this drying technology reduces micro-traumatizing of grain crops, which entails a high quality product, the growth of the seeds' germination on a long-term storage. According to the test results, after the SHF drying the retardation of the effect of a product's self-heating in storing bunkers occurs in 10 times, and the acidity growth of oil crops decreases.

A microwave drying's advantage is that it does not have a heat transfer from the heater. The air heating, its transportation, a heat transfer, the unavoidable heat losses occur at each stage of a conventional drying, the efficiency coefficient of the installation is about 50–60 %. The heat source of the SHF drying is a product itself, that's why the above-mentioned losses don't exist while preserving the drying product's quality, which improves the quality of the installation's efficiency coefficient up to 90 %.

Figure 2.8. Home-made grain installation ACT-3

The qualitative changes of the produced SHF grain dryers are characterized by:

– high performance;

– small dimensions and weight;

– cost effectiveness and no grain contamination with carcinogenic products of combustion;

– heating occurs inside of grain;

– no grain micro-traumatizing, unavoidable using the conventional drying methods;

– possibility of seeds' treatment with high moisture; the usability of the complicated drying regimes;
– improvement of seeds' germination in a processing of the seed stock;
– ability to transport and place a grain dryer anywhere;
– a low cost of the grain processing and service charges
– fire safety.

The development of the mechanized grain drying does not deny the capabilities of a rational use of a solar drying, which has a variety of advantages over a heat drying. Using a solar drying it's possible to reduce the moisture content of the grain mass by 1–2 % or more during harvest. The grain mass, spread in a thin layer of fill, can be heated with the heated rays to a temperature of 35–50 °C. The heating of the grain mass with the sun leads not only to a decrease in moisture but also has a very positive effect on its condition.

In the freshly harvested grain a solar drying promotes its after-ripening and makes the lots of such grain more stable to store (a partial sterilization of grain mass from micro-organisms occurs). As a result of the heating of the surface's fill and air, an intensive evaporation of moisture from the upper layer of grain happens around it. In windy conditions the evaporation is particularly successful, since water steams evolved do not stay on the fill's surface.

3. Energy-saving in buildings and constructions

Today energy development in the Republic of Belarus is on the second stage, which involves an intensive way of development using high-efficient energy-saving technologies of the new generation.

However, it's essential to remember about such spheres as socially-oriented objects and a housing stock including modern agricultural settlements. The shares of the heat and electric energy consumption in the housing and public utility sector are shown the diagram (Figure 3.1). Moreover, it should be noted that from year to year the share of the heat energy remains practically unchanged and constitutes at about 60 % of the total consumption.

Regarding the socially-oriented objects in rural areas, their energy consumption is in a more apparent predominance of the heat energy share in the balance of the total energy consumption (Table 3.1).

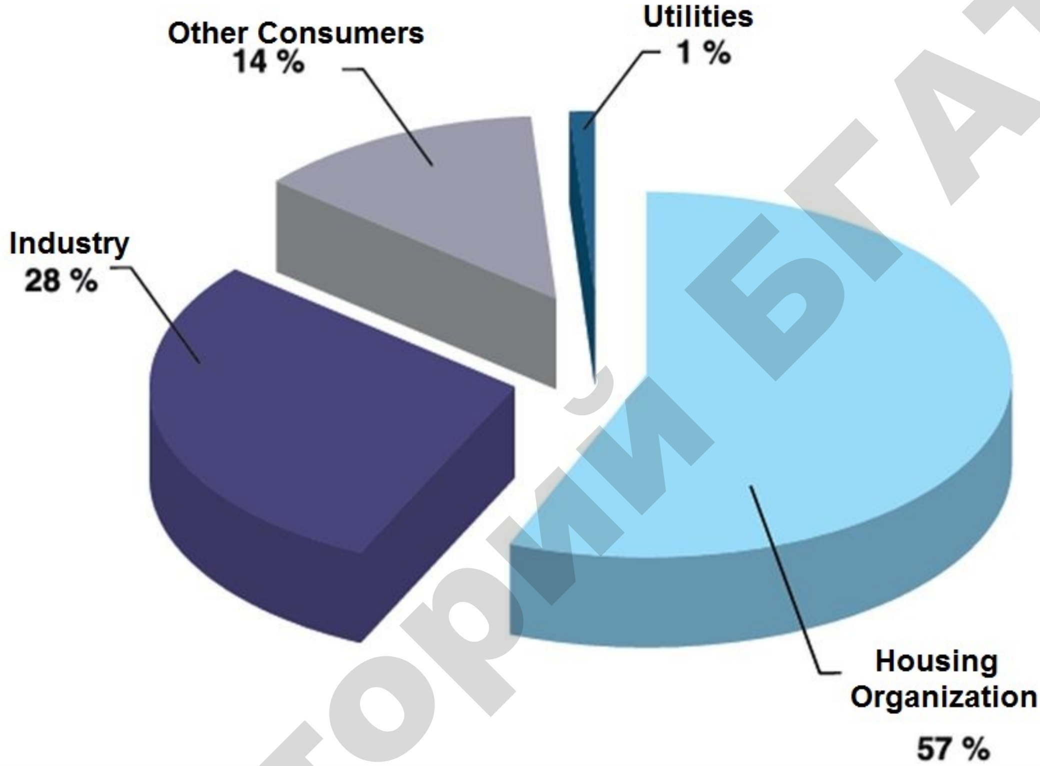


Figure 3.1. Heat consumption structure in the Republic of Belarus in 2012

Table 3.1. Energy consumption structure of social objects, %

	Research object				
Type of energy resources	"High school №1", Chashniki	"Grozovskaya High school"	Volmyansky cultural centre	Social psychological center	School № 78, Minsk
Heat energy	87,2	90,6	99,0	65,9	89,5
Electric energy	12,8	9,4	1,0	34,1	10,5

With regard to energy-saving, the buildings of the 60–80th years are the most problematic, they have an average value of the wallings' (walls) thermal resistance of about 0,34 m^2·°C/W and the light area – 0,15 m^2·°C/W. Thermal resistance regulations of the buildings' wallings have been adopted in residential and public buildings since the first of July, 2009. They are 3,2 $m^2·°C/W$ for the exterior walls; the infilling of the light area – 1,0 $m^2·°C/W$ [58].

The required values of thermal resistance of a heat transfer in some European countries are presented in Table 3.2.

Table 3.2. Termal resistance of a heat transfer in some European countries

European countries	The year of the regulation's acceptence	Heat transfer resistance, $m^2·°C/W$		
		Walls	Windows	Roofs
France	2005	2,78	0,56	5,00
Denmark	2006	5,00	0,67	5,56
Norway	2007	5,56	0,83	7,69
Sweden	2008	5,56	0,76	7,69
Belgium	2008	2,00	0,67	3,33
Germany	2009	3,57	0,77	5,00
Finland	2010	5,88	1,00	11,1
Great Britain	2010	5,55	0,67	6,67
Italy	2010	3,03	0,50	3,45
Netherlands	2011	3,45	0,45	3,45

The following basic errors, made by the staff operating the equipment, can be referred to the weak points of a rational use of heat and electric energy at the sites of a social sphere:

– a decorative closure of heating appliances (different lattices, special panels and a complete closure in niches);

– building glass stones' usage instead of standard windows (typical of school workshops and gyms);

– heating appliances' connection with the improperly selected pipes' diameter of the closing areas: a pipe diameter of the closing area is equal to or more than pipes' diameter connected with a heating appliance;

– laying of the buildings' natural ventilation system (for example, with siding or plasterboard panels);

– an incorrect placement of lighting fittings concerning windows (perpendicular to the windows' line that prevents from regulating while increasing (decreasing) natural light);

– windows' blanking with decorative curtains, with a large amount of flowerpots and other items on the windowsills in the premises.

Besides, it's necessary to take into consideration "cold bridges" (Figure 3.2), which can be frequently found in the old houses' constructions and in houses having a long operation life.

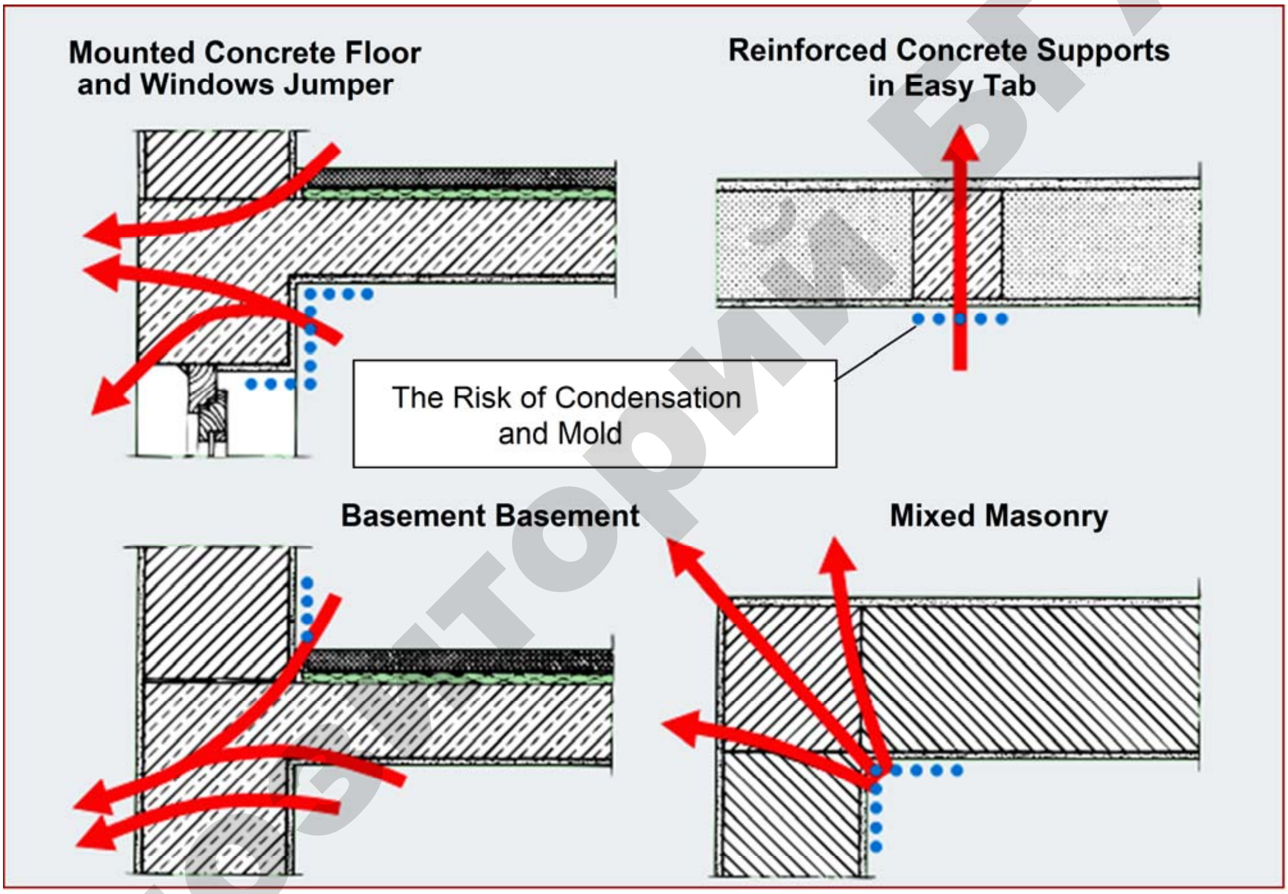


Figure 3.2 . Typical "cold bridges" under construction

Typical heat losses in individual houses, built before 1993, as a rule have the values presented in Figure 3.3. In the multi-storey buildings (built before 1993, Figure 3.4) heat losses are the following: walls – 42–49 %, windows – 32–36 %, an entrance porch door – 5–15 %, basement and attic floors – 11–18 %.

Judging by the facts stated above, it's possible to offer the following low-cost measures:

– building joints' sealing, additional roof's heat insulation;

– repair and sealing of windows, doors, vestibules;

– area reduction of windows' openings with the mounting of a window with a transparent film in the frame space;

– local insulation of walls' areas including niche insulation below the heating appliances;

– insulation of floors, basements and closures over them;

– heating pipes' insulation in the heating units, heating points and apparatus floors (if there are);

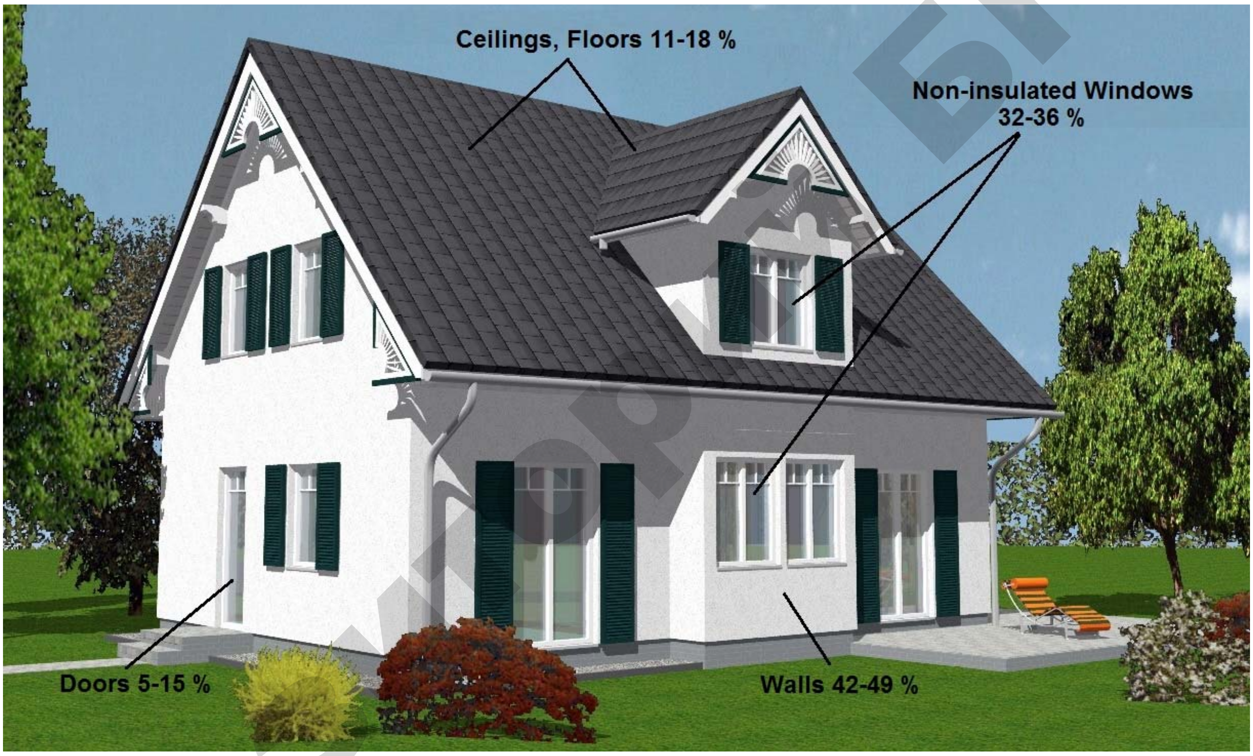


Figure 3.3. Heat energy losses due to the wallings of an individual dwelling house

– opening of heating appliances (removal of decorative lattices);

– use of infrared heaters to heat large buildings (sports and assembly halls);

– a proper connection of heating appliances;

– introduction of modern lighting systems with an automatic regulation of a luminous flux;

– rational placement of lighting fittings taking into account the normalized illumination on the working surfaces;

– use of a local lighting system (in reading rooms and libraries);

– an outdoor lighting should be done with the application of the LED lighting fittings (150 W) and a lighting control system;

– optimization of the natural light's usage;

– a proper usage of finishing materials (reflection coefficients vary).

The fuel economy's significant reserves lie in a rational architectonical design of new public buildings. This economy can be achieved due to:

– an appropriate choice of buildings' form and orientation;

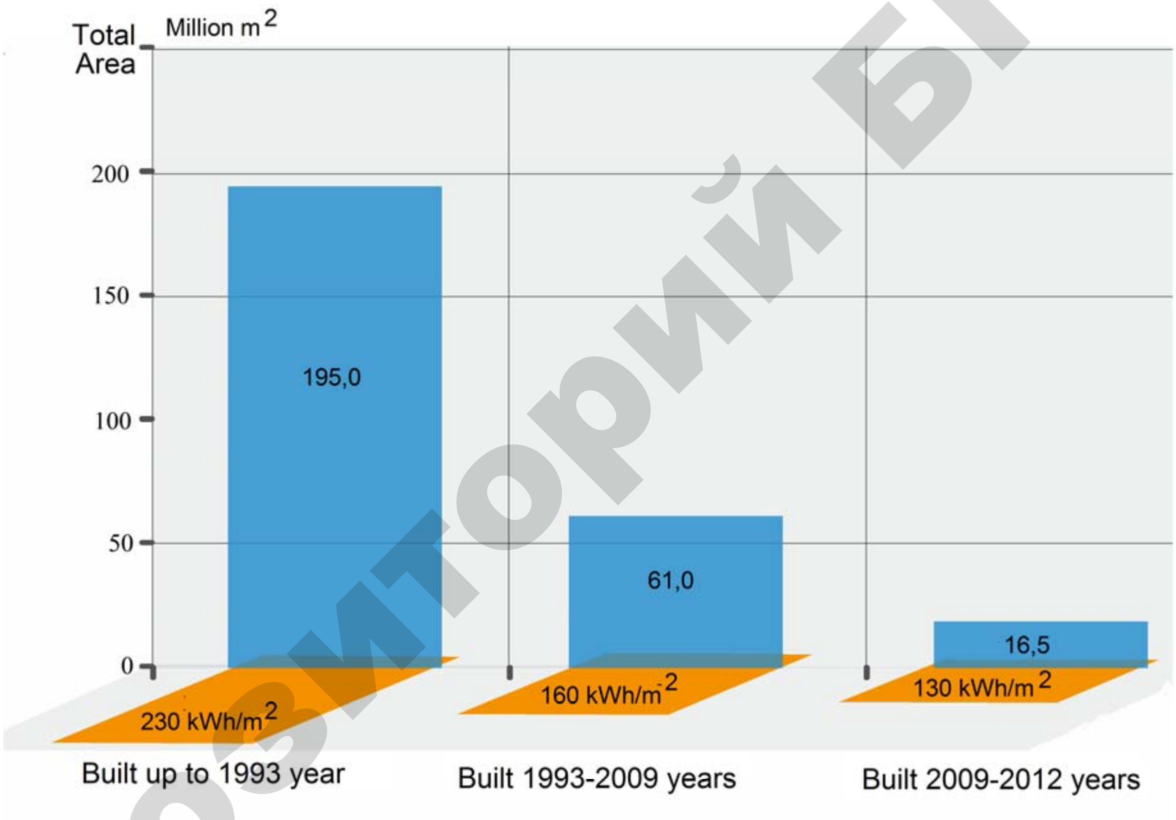


Figure 3.4. Distribution of the housing stock's areas according to the specific annual heat consumption depending on the building's year.

– volume-planning decisions;

– selection of heat-shielding properties of the external wailings;

– selection of differentiated walls' light on the sides and a window size;

– motorized insulated shutters' application in dwelling houses;

– application of wind-preventing devices;

– rational arrangement and control of artificial lighting instruments.

In addition, a certain economy can be created due to the use of the central, facade, storied, local and individual, programmatic and intermittent automatic control, and use of electronic computing machines (ECM) equipped with the blocks of the program and optimal control of energy consumption.

According to numerous energy surveys, heat overconsumption occurs in buildings, mainly, due to:

– a lower heat transfer of wallings compared with the calculated resistance;
– premises' overheating, especially in transitional periods of years (autumn, spring;
– heat losses due to non-insulated pipe-lines of the heating system;
– heat supply organizations' disinterest to reduce heat consumption;
– increased ventilation in the premises of lower floors.

The most important directions of energy economy for a perspective period are the following:

– development of the energy plants' control systems with the use of modern means of automated control system (ACS) on the basis of micro ECM;
– combined heat usage of all types of secondary energy resources;
– an increased importance of the central heating power plant ensuring the combined generation of electric and heat energy;
– thermo-technical characteristics' improvement of wallings, administrative and industrial buildings;
– constructions' improvement of heat sources and heating systems.

Providing heating consumers with the control and regulation means of consumption reduces the costs of energy resources at least by 10–14 %. On condition that the change of the wind's speed is taken into account – up to 20 %. Moreover, the application of a phase-by-phase regulation of the heat-supply for heating gives a possibility to reduce the heat consumption by 5–7 %.

The 10 % saving is reached thanks to an automatic control of the central and individual heating units, reduction or elimination of the systematic water losses.

The main aspects of activities on the heat energy saving in the buildings' heating supply systems are:

– development and application while planning and producing technically and economically substantiated progressive norms of heat and electric energy consumption to exercise a saving regime and their most effective utilization;
– accounting organization of heat supply and consumption;
– development and implementation of the organizational-technical measures to eliminate wasteful heat losses and leakages in the networks.

While working out the plans of organizational measures to economize on heat energy in buildings, it's essential to keep in mind the activities' execution in the following directions:

– an increase of heat-shielding properties of the buildings' wailings;
– reliability improvement and automation of the heating systems with a centralized heat supply;
– development of constructions and the systems' calculation methods of the intermittent buildings' heating with a variable heating regime;
– development of reconstruction methods of the existing heating systems when a technological process of the buildings' exploitation changes;
– heating systems' improvement;
– improvement of the connection patterns of the heating systems to heat networks.

"Thermoshuba" is used to ensure old buildings with heat insulation (before 1993, Figure 3.5) and reach normalized thermal resistance under modern buildings' construction (Figure 3.6).

"Thermoshuba" is a multilayer, lightweight construction with a thin plaster layer, designed for heat insulation of the external walls of residential and administrative buildings. The system "Thermoshuba" produced by "SARMAT" is the first in Belarus technology of the heat facades' modernization, which has been recommended for a wide use in construction since 1996.

The advantages of "Thermoshuba":

– possibility of the year-round operation on the facades at a temperature from –5 °C to +30 °C;

– buildings' insulation of any number of storeys without the reinforcement of walls, pinning, resettlement of dwellers;

– effective sound insulation of walls;

– an increase of a repair period between the buildings' operation up to 25 years;

– assurance of an optimal temperature-moist microclimate in the premises;

– resistance to temperature differences of "Belarusian winter";

– problem solving of "cold bridges" concerning jumpers, metal beams, balcony slabs and floor slabs;

– improvement of resistance of the exterior walls' heat-transfer up to the standard indicators.

The external walls' insulation system with effective slabby materials with a protective layer from a thin plaster layer armored with glass-cloth can be often found at the sites of Belarus (appendix 1) [51]. Now "Thermoshuba" dominates, it was introduced by Special Construction Technological Bureau (SCTB) "SARMAT"; it has confirmed its high qualities in dozens of sites. Making a practical contribution to the implementation of a heat rehabilitation programme of the house stock of the Republic of Belarus, the company "SARMAT" insulated in more than 100 objects with a total area of 140 thous. m^2 in 1994–1998.

Residential houses in the settlements for ex-habitants of a Chernobyl zone, a new building of the railway station, the indoor skating rink in Gorki Park, the 9th or 12th-storeyed residential houses in Ohotskaya and Chekalina streets and in a micro-district Uruchcha, the 12th-storeyed residential house in Storozhevskaya street, the 16th-storeyed monolithic house in Landera street, a dormitory consisting of 300 places in Kalinoyskaya street in Minsk; buildings of the branches of the National Bank and Foreign Trade Bank in Borisov and Pinsk; residential houses in Bereza, Vileyka and Vitebsk, Zaslavl, Mogilev, Osipovichi, Shklov and Brest – all the mentioned above belong to these objects.

The insulation works were done on the newly constructed buildings to increase thermal resistance of the wallings up to the value of the appropriate norms, as well as in the exploited freezing houses with crumbling facades, wet walls in rooms, in the majority of which the temperature didn't rise above 8–20 °C.

Antifreeze polymer mineral glue "Sarmalep-M" was tested in practice. It proved its high properties while working at a temperature of the ambient air up to –120 °C. Therefore, in our conditions the buildings' heat insulation according to the "thermoshuba" technology can be carried out virtually all year-round. "SARMAT" gives a 10-year warranty on the quality of the buildings' heat insulation.

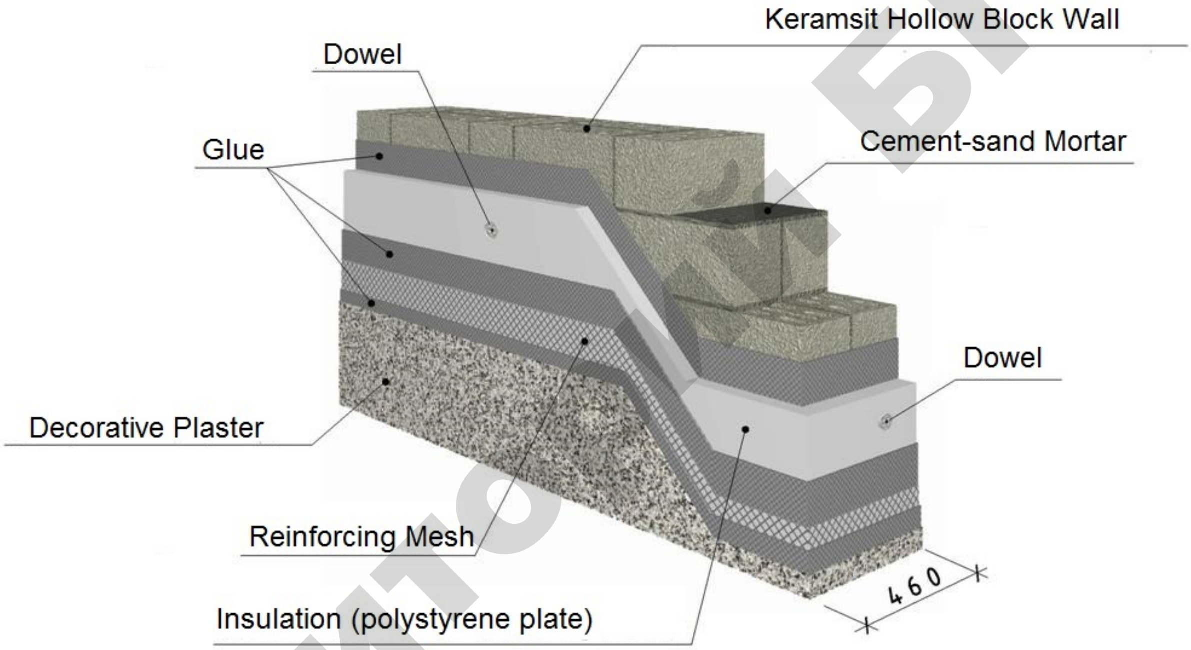


Figure 3.6. A modern building's wall covering based on technology "Thermoshuba"

To reduce the heating costs of the energy inefficient buildings, a set of measures was developed called thermal rehabilitation ("heat renovation" and "thermoshuba").While rehabilitating buildings a number of nuances invisible to the eye should be taken into account, such as thermal conduction of walls, cold bridges, air infiltration and others. The building's energy certificate is used to take into consideration all the parameters making up a building's energy efficiency and provide information in a simple and visual form. This document has already been introduced in several European countries (Germany, Poland). In our country it has been designed and recommended for the use by IPO "Ecopartnership".

The building's energy certificate is a page of A4 format (Figure 3.7), to which a protocol of about 10 pages is attached. The certificate shall contain the certificate number, that'll render assistance in creating a republican database of building's energy efficiency. The building's purpose and address; the date of the certificate's issue; the duration of validity (10 years), who issued, with the organization's requisites conducted the certification; the building's type (existed or new); the year of construction; the year of reconstruction (if conducted); the calculated area, are stated in the certificate. For illustration purposes there is a picture of an appropriate building in the certificate. The building's energy labeling is also easy to read, it represents itself a colour scale with the indicated energy efficiency class to which the building is related, and a concreate figure of energy consumption per square meter annually. It's also possible to find here electric energy and energy consumption for hot water supply. Emissions of greenhouse gases equivalent to the CO_2, produced by the combustion of fossil fuels, required to ensure the building's energy needs are stated in a lower left corner with the designer's approval. This characteristic is a reverse side of energy consumption. Further it can be used to develop alternative energy sources disconnected with emissions of greenhouse gases.

The protocol is attached to the energy certificate. It outlines the key indicators and calculations on the basis of which the certificate is issued. The implementation of the building's energy certification after construction allows identifying the main sources of energy losses. Further it allows calculating the necessary amount of heat rehabilitation measures. The after heat rehabilitation certification makes it possible to evaluate the quality and efficiency of the conducted activities. The attached energy certificate near a porch informs the residents about a source of the heating costs and the contribution of their houses into the solution of the global problem of a climate warming.

At present, the given certificate form, developed in the framework of the project "International cooperation for the development of energy efficiency in Belarus – the buildings' energy certification promotion", is advisory in nature. Creating the buildings' certification system will lead to the quality improvement of the activities concerning buildings' heat rehabilitation as well as to the energy efficiency improvement of a building industry in general. Among the positive results of the introduction of the buildings' energy certification, in comparison with the use of other tools (energy audit, energy performance certificate), are the following:

– certification is a more accessible method for a preliminary assessment of the buildings' energy efficiency, in comparison with energy audit;

– energy certificate's development is significantly cheaper than the audit, because it doesn't require a lot of labor costs and measurements with the expensive devices;

– energy certification creates incentives for individuals and organizations to implement energy-saving measures on their own premises, without waiting for thermo-renovation and overhaul repairs at the expense of state funds.

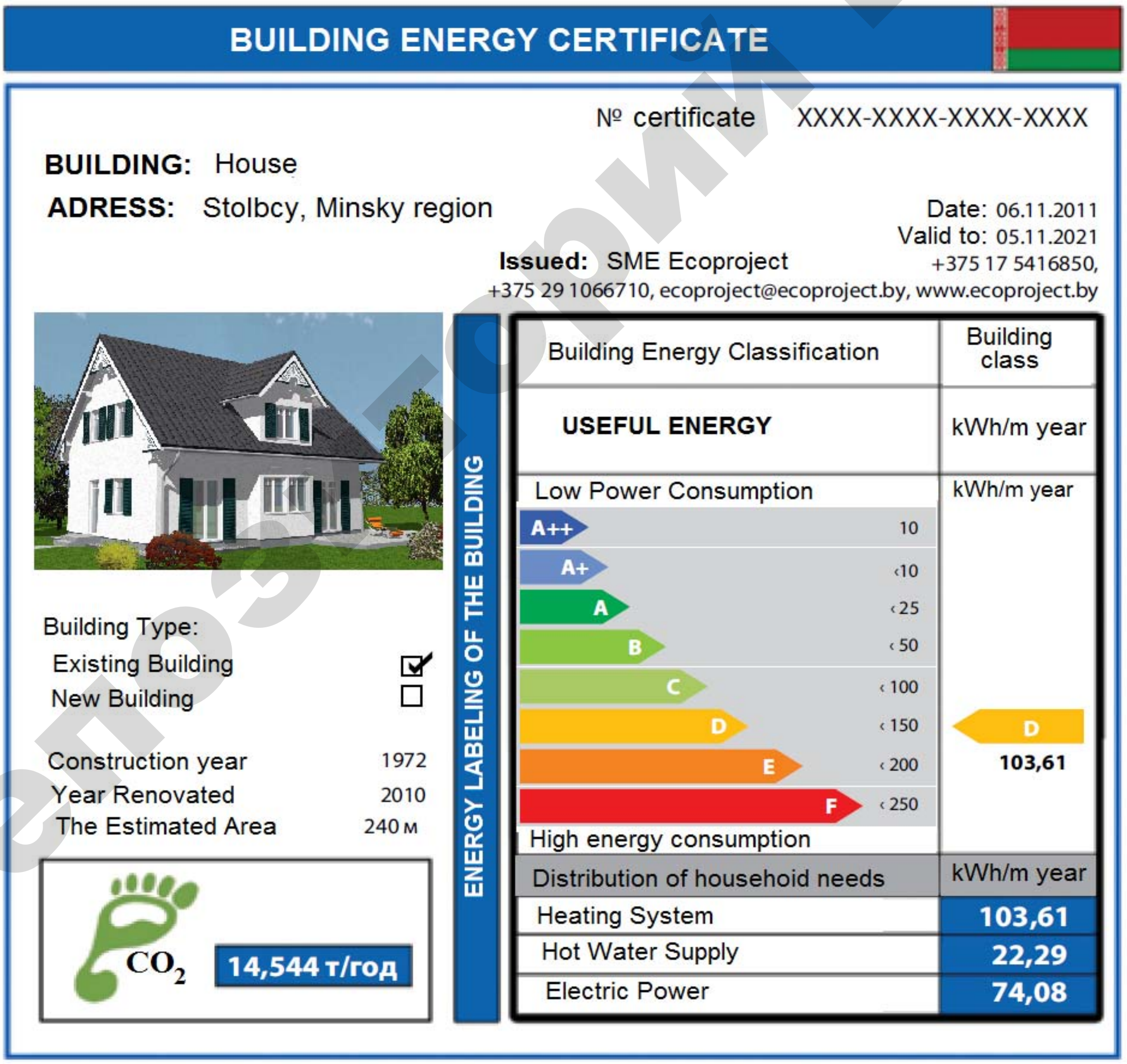


Figure 3.7. The building's energy certificate (title page)

In Belarus, the buildings' energy certification can be viewed as a system of the buildings' conformity assessment, as a form of construction products, requirements established by legislative acts and standards regarding the production in the field of energy efficiency.

The proper use of household appliances is of utmost importance for the energy efficiency improvement in housing and public services. The annual consumption of electric energy with the main types of household appliances is presented in Figure 3.8. It is worth noting that in 2006 refrigerators and freezers were the leaders in energy consumption. Progress in the household appliances' certification has eliminated all costly appliances from the market, especially refrigerators, freezers and washing machines. However, for a further reduction of energy consumption it's necessary to use different exploitation methods of household appliances and the following recommendations, developed by the leading experts in technology production throughout the world:

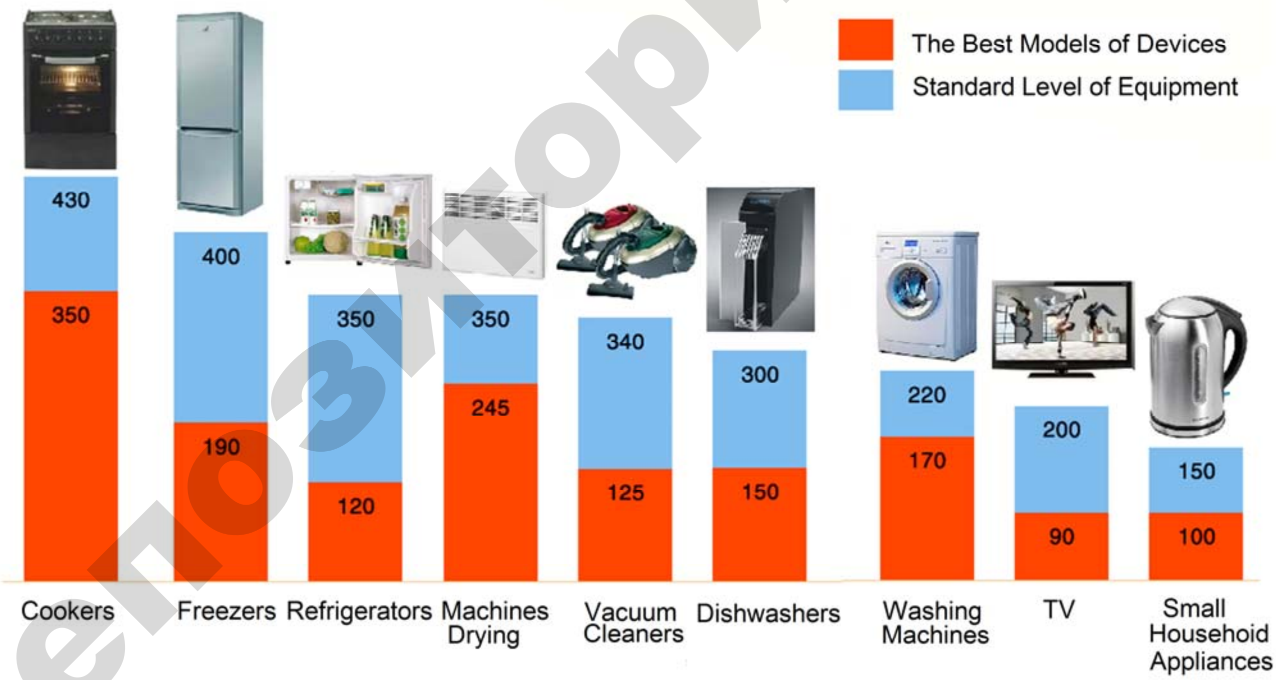


Figure 3.8. The annual electric energy consumption with household appliances

– while cooking it's necessary to close pans with lids, so food is cooked faster;
– it is undesirable to boil water more than required;

– if you are cooking on an electric stove, use the residual heat – turn off the burner for a while until the food is cooked;

– place the refrigerator in a cool place, rather far off heating radiators and an electric cooker;

– make sure that the seals on the refrigerator's door have not been damaged, and the rear wall must be always clean;

– don't place the refrigerator close by the wall, leave a gap for ventilation;

– defrost the refrigerator regularly;

– use special nozzles on the shower and a faucet, reducing water consumption;

– save while washing, setting a lower temperature on the washing machine, it can reduce energy consumption by 80 %;

– wash with a full load of the washing machine;

– working at the table, use the table lighting – it is brighter and consumes less energy;

– install the energy-saving bulbs where light is used frequently and for a long time (in the corridor, in the bathroom).

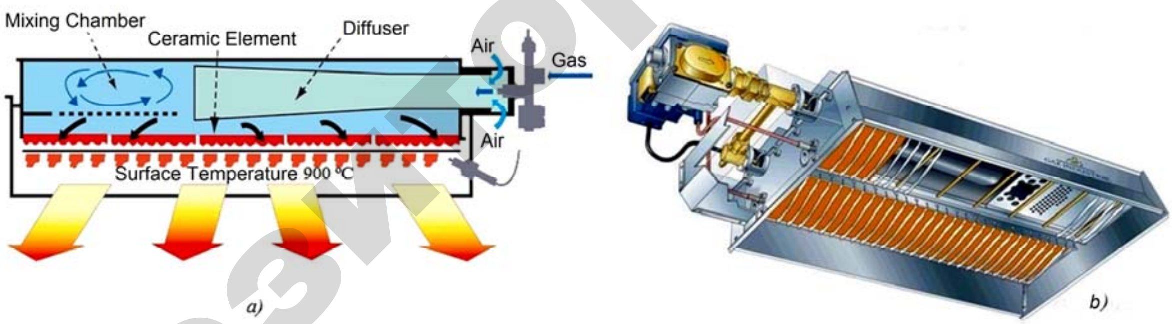


Figure 3.9. An infrared gas heater:
a – a basic diagram of the heater's functioning; b –a general view

– turn off the light when it is not needed, switch off a radio, a television, a computer and other electronic devices when they are not necessary;

– ventilate the room by opening windows wide for a short time (it is desirable not to use the heating appliances at the same moment);

– electronics and household appliances consume electricity even in a sleep mode (turn off the devices completely, removing the plug from the socket);

– do not leave chargers plugged into a socket.

Infrared gas radiators are used as the heating equipment to save energy in the communal premises of a large area. Such radiators are mainly arranged under the ceiling, and they represent themselves a housing element with a turned reflector to the floor's side, at the bottom of which there is a ceramic nozzle consisting of flat plates on which there are a lot of small holes.

A combustible mixture is supplied in the space between the housing element and a nozzle, and it heats ups the plates to a very high temperature, after than a gaseous combustion process occurs on a red-hot surface of a ceramic nozzle, and it in its turn produces heat radiation in a heated space. While using infrared radiators the products of gas combustion are practically absent, and their remains are removed from the premises by means of the ventilation system.

In the residential premises the air temperature of +18 °C, at the level of humans' head, is considered to be appropriate for human beings to feel normal and comfortable. If the traditional heating systems are used, than the temperature at the floor's level is above +16 °C (Figure 3.10*a*).

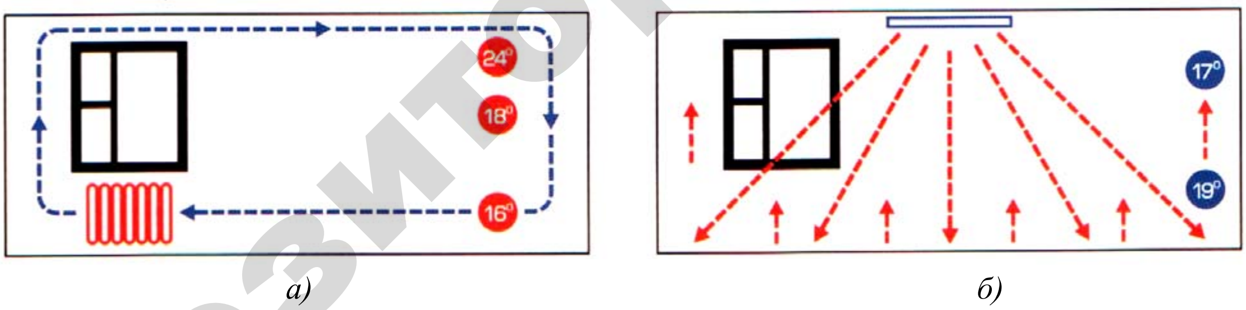


Figure 3.10. Air temperature distribution in the premises with different heating systems: a – traditional convection heating system; b – heating with infrared radiators

Using the infrared heating system, the temperature at the floor's level becomes 3 °C, in other words it increases up to 19 °C (Figure 3.10*b*). This reduces the premises' heating by 2–3 °C and accordingly saves energy.

In addition to gas infrared heaters, electric heaters with IR-radiators are effectively used (Figure 3.11). Electric energy converted into heat energy in THE[2],

[2] *THE – tubular heating elements.*

heats the radiating plates of the IEI heaters or is reflected from the reflector of the OEIP heater. 70 % of energy is delivered to humans, equipment or wallings, later releasing the warmth into a room, heating up the air. In other words, there is no need to warm the air in the whole room to ensure a comfortable temperature.

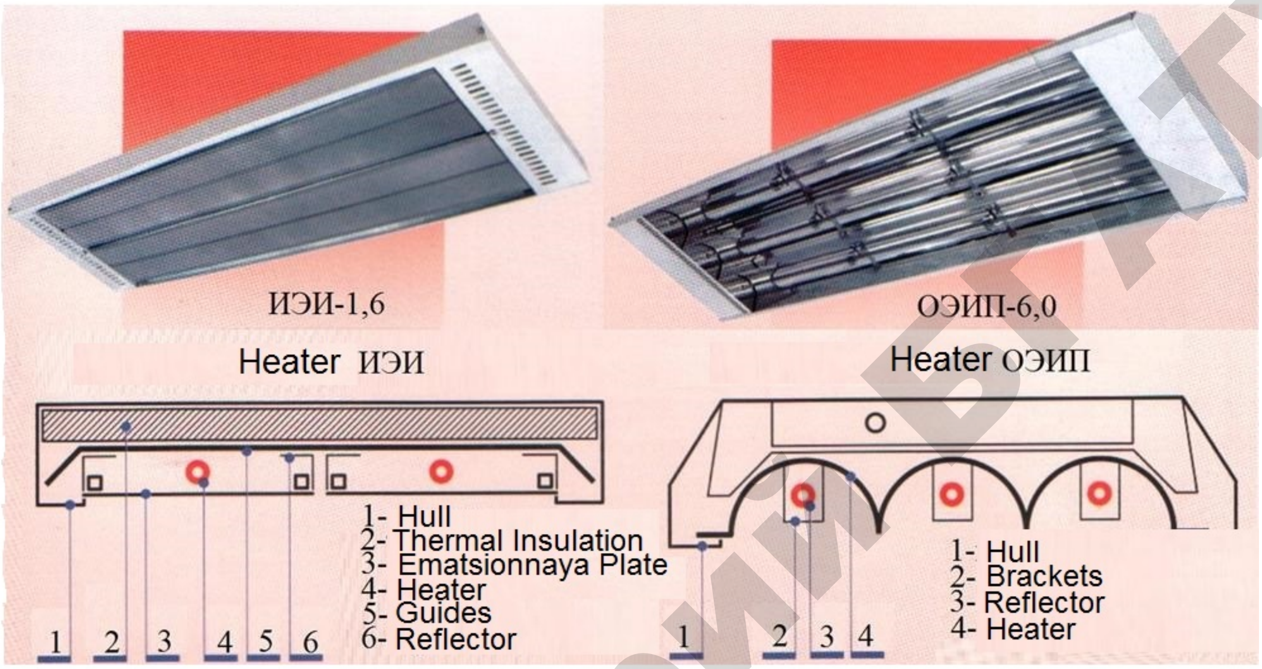


Figure 3.11. Electric infrared heaters produced in the Republic of Belarus

The examples of such premises are:

– factory buildings, industrial buildings;
– warehouses, high-bay warehouses;
– health care institutions;
– railway stations and airports;
– motor shows, car washes;
– trade and exhibition halls, covered markets;
– sports and entertainment facilities, indoor tennis courts;
– training covered landfill sites;
– cottages, garages, summerhouses, apartments;
– gas stations and service stations;
– other objects of the housing and public utility sector.

It should be remembered that infrared gas heaters are considered to be the most efficient equipment from the entire heating technology. The basis of a heater's operation is the sun's principle when the heat in the form of rays is transmitted directly into a heating zone. All heat energy is absorbed in a lower part of a two-meter room. The heat rays do not heat up the air.

The heating issue is particularly sharp when it's necessary to heat up large industrial premises with local working places. In this case, the room is divided in the heated zones, whereby the heaters "are working" only where there are people.

Furthermore, in the premises a heat transfer surface of the floor and objects heated up by infrared heaters exceeds a heat transfer surface of the traditional heating appliances in 5–10 times. This effect is achieved by the equipment installation on the ceiling; as a result large horizontal surfaces are heated. Therefore, the air volume is heated up to a desired temperature much faster. To maintain a required temperature the system is switched on less frequently than usual, thus consuming less energy. With an increase of the heaters' suspension height (for example, in warehouses) the heat transfer surface increases even more, so does efficiency. There is no need to maintain a high temperature in the working premises at night, on weekends, as an infrared heater can create favorable conditions during 30–60 minutes, while radiators – per calendar day.

One of the heating variants of classrooms at college (Germany) with gas heaters is shown in Figure 3.12.

The main advantages of infrared heaters in comparison with traditional heaters are the following:

– no dust and volume displacement of the air space;
– a very low inertia of the temperature setting;
– no necessity to heat the air upper layers (thermal radiation is directed strictly down);
– energy savings is 20–50 % in comparison with the convection heating systems;
– zone heating possibility;
– it does not take up a useful space at the bottom of the premises.

As a rule electric energy is used as means for a local heating of personal working places of companies and firms, and also for houses with small children. The premises' electric heated floors, which convert electric energy into heating, are referred to the places of a local heating (Figure 3.13).

Figure 3.12. The gas infrared heaters' usage in covered pavilions:
1 – a general view of a pavilion; 2 – heaters' placement along the longitudinal wall, where training working places (desks) are found; 3 – a general view of a gas heater

Nowadays the aquatic and heated floors' manufacture throughout the whole room is very popular for an individual housing construction. An aquatic and heated floor is a useful heating system, an alternative to a classic radiator heating system (contrary to a popular existing opinion). The essence of an aquatic and heated floor is the arrangement of a mini-pipelines' network (the heated floor's circuit, Figure 3.14) between the floor and floor covering, through which a heat carrier circulates – the heated water is about + 35–45 °C. Therefore, an aquatic and heated floor is also called "low temperature heating system". In total, heat losses attributable for each degree of the difference between the average temperature of the floor's surface and a room temperature are equal to 11,5 W/m^2. It means that in order to maintain the premises' temperature at 20 °C with the heating load of 50 W/m^2, the temperature of the floor's surface should be at 4,5 °C higher than the temperature in the room.

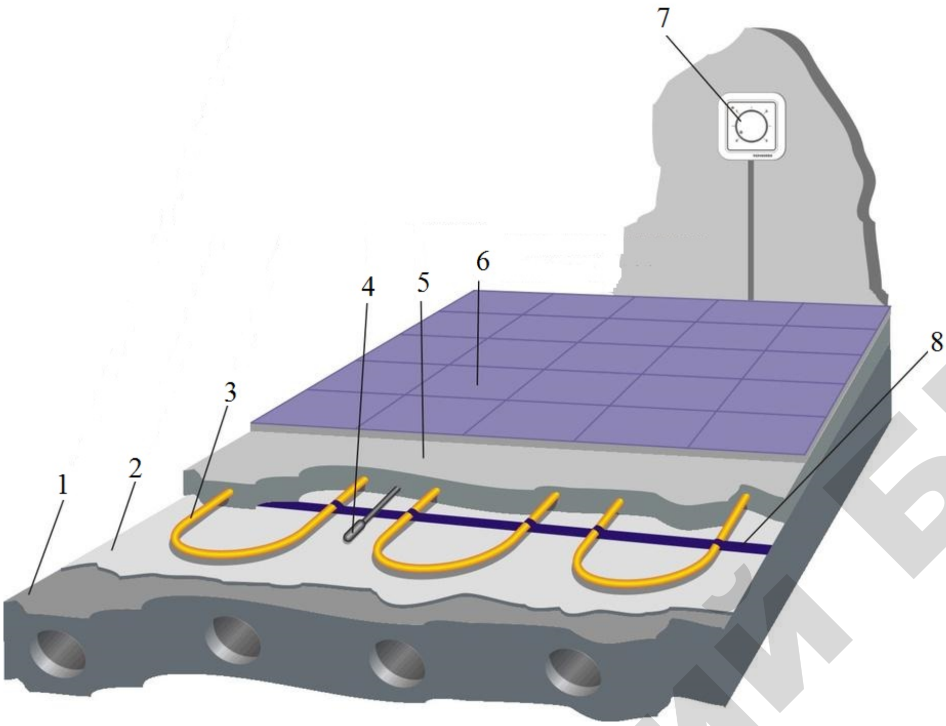


Figure 3.13. Heated floor's installation in the premises with the use of a heating cable: 1 – flashover; 2 – heat insulation; 3 – heating cable; 4 – temperature sensor; 5 – cement and sand strainer; 6–the main floor's covering (ceramic plates, linoleum, fitted carpet); 7 – thermostat; 8 – mounting band

This worth paying attention to the fact that the operational lifetime of the heated systems is very high, and depends only on the viability and the pipe's permeability, through which a heat carrier flows. And it's at least 50 years. In contrast to the electric heating the systems, the heated floor is quite repairable. There is only a metal and plastic pipe in concrete, which is easy to clean from deposits in 10–15 years.

Thanks to new technologies it has been possible to avoid too high temperatures of the floor's heating, which really provoked a poor circulation and the legs' swelling. Having reduced the air flows drastically, drafts, air turbulences and movement of dust indoors, classical inconveniences of the convection and radiator systems have also disappeared. With the help of the heated floor's systems man feels the same comfort level at the air temperature on average at 2 degrees lower in comparison with the traditional systems: in other words, the feeling of a comfortable temperature appears, that is 22–23 °C, whereas in reality a thermometer shows only 20–21 °C. This effect is a result of the lower heat dispersion to the outside due to heat insulation using heat insulation panels, and energy-saving in accordance with the new regulations.

Figure 3.14. The heating system based on an aquatic and heated floor:
1 – the aquatic floor's device; 2 – the pipes' assembly unit to the heating system

In terms of energy resources' saving it is enough to imagine that by lowering temperature in a room, the energy-saving corresponds to 7–8 % for each degree.

According to the above-mentioned reasons, the heated floor's system is easily integrated with such sources of energy as solar panels, condensing boilers and heat pumps. Thanks to the heated floor's system a living space is used more fully. Indeed, the absence of radiators gives freedom for a room's design, eliminating aesthetic problems associated with radiators. Heat insulation panels made of cellular polystyrene with a steam barrier can absorb a walking noise, performing an important function of sound insulation between residential floors. Due to an increased strength of panels and pipelines, the operational lifetime of the radiating heated floor's system is unparalleled.

The use of convectors built in the floor is a perfect solution to save energy resources in order to maintain the microclimate's parameters in the working areas intended for offices, conference rooms and similar (Figure 3.15).

Figure 3.15. Convectors built in the floor with the WSK natural convection

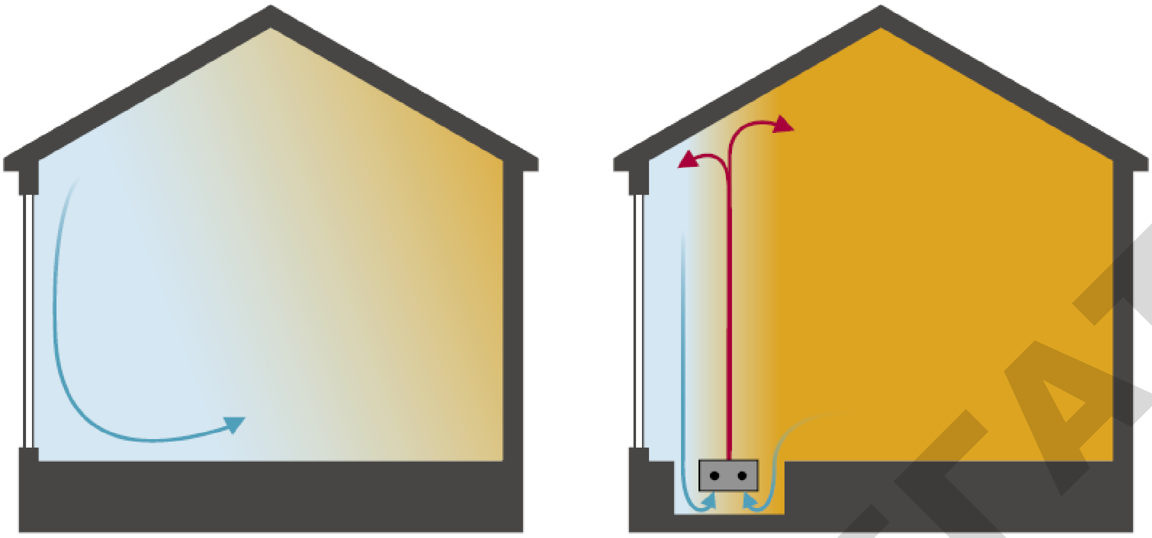
The streaming down heavy cold air from the glassed facades and the lighter warm air climbing towards create a natural air flow. This heated air creates a heat barrier to the glassed facade and prevents from a further or enhanced cooling of the room. In addition, it prevents from the discomfort emergence on the floor because of the cold draft (Figure 3.16).

The advantages of the convectors built in the floor are the following:

– protection against the cold air admission from the windows;

– windows' preservation in a non-weeping state at any external and internal temperatures;

– residual heat protection in a combination with the panel heating underfloor;



a *б*

Figure 3.16. The use of the convectors built in the floor:
a – cold air penetration with the usual system of big windows in the room; b – cold air blockage with convectors built in the floor

– a continuous heating (with the corresponding consumption);

– energy-saving using a special ventilation system (a strong injection effect is produced on the length till 5 m, Figure 3.17).

Convectors built in the floor are produced of three types according to the hot air delivery, capture, and the cold air delivery (WSK, GSK, QSK).

Technical characteristics of the WSK convectors are illustrated in Table 3.3. A standard length is 1000–5000 mm.

Table 3.3. Technical characteristics of the WSK convectors

	WSK 180	WSK 260	WSK 320	WSK 410
Convector's width, mm	180	260	320	410
Convector's height, mm	90, 110, 140, 190			
Heat exchanger	double-pipes	double-pipes	three-pipes	four-pipes
Ribbing's width, mm	80	80	147	164
Working pressure, bar	10 (optional till 16 bars)			

Technical characteristics of the GSK convectors are shown in Table 3.4. A standard length is 1000–5000 mm.

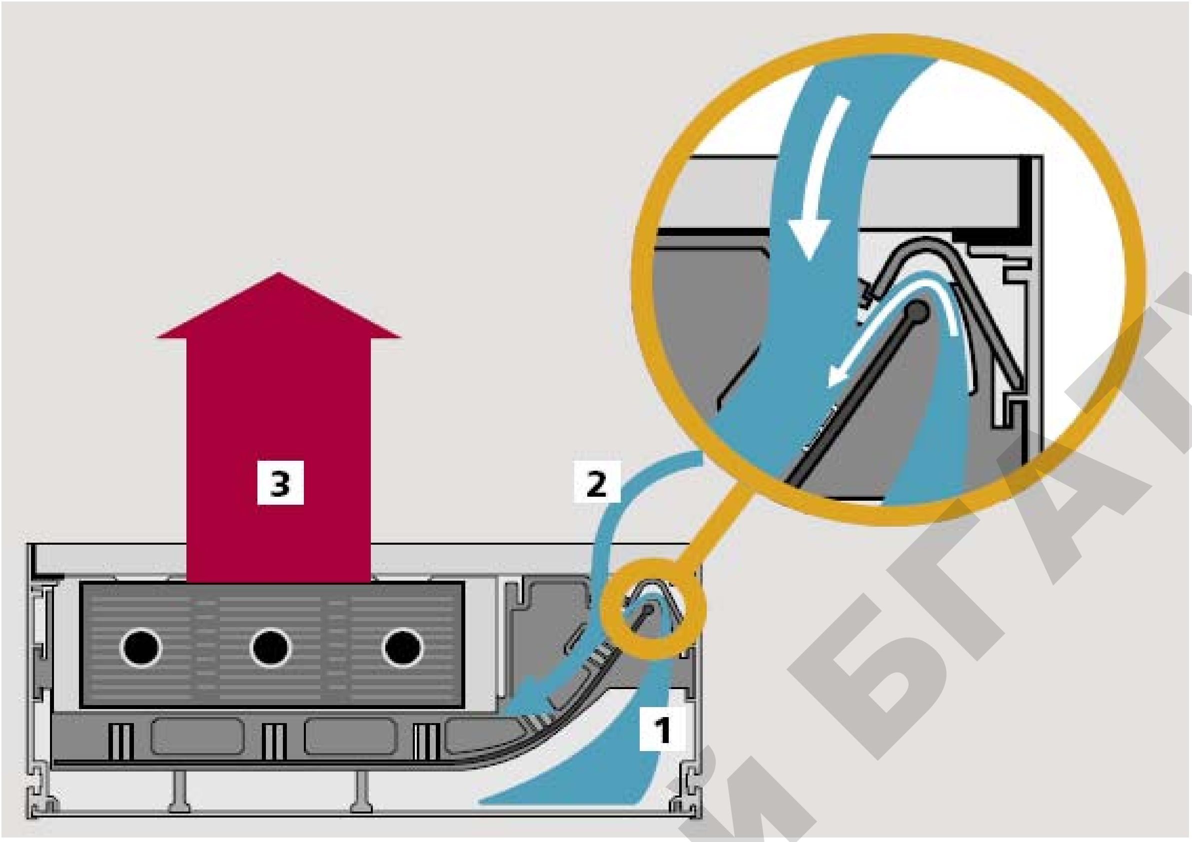


Figure 3.17. The patent ventilation system producing a strong engineering effect on the length up to 5000 mm:
1 – cold air delivery; 2 – cooled air (cold air slipping); 3 – heated air for the room's heating and protection from cold air flows

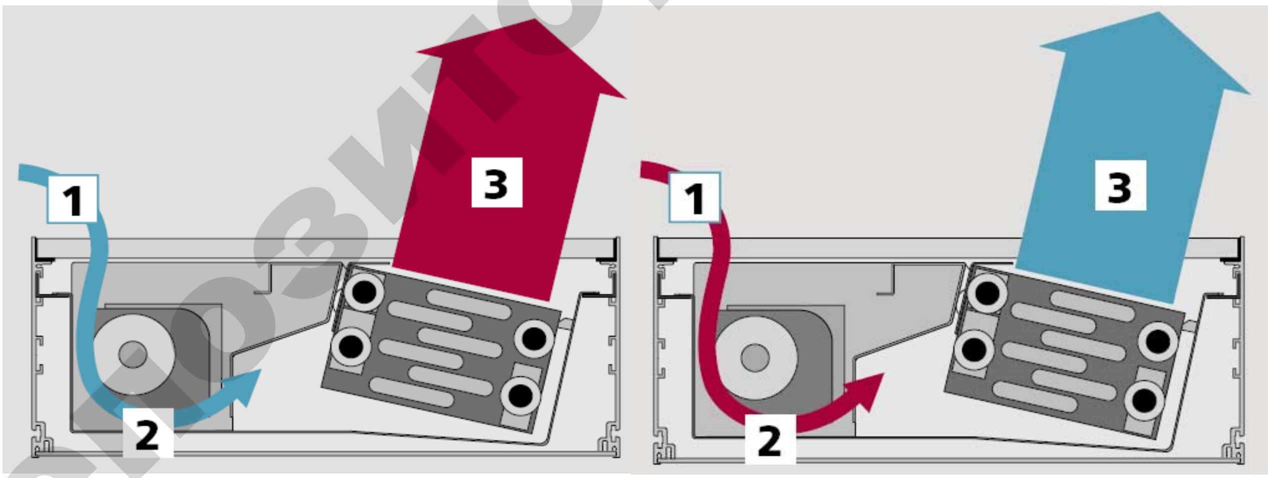


Figure 3.18. The main operational regimes of the QSK convectors built in the floor:
a–a heating regime (1 – the cooled air; 2 – induced cold air is distributed through the heat exchanger along the turbo blower's length; 3 – heated air); b–a cooling regime (1 – the heated air in the room; 2 – induced hot air is distributed through the heat exchanger along the turbo blower's length; 3 – cooled air)

Table 3.4. Technical characteristics of the GSK convectors

	GSK 180	WSK 260	WSK 320
Convector's width, mm	180	260	320
Convector's height, mm	115–155		
Heat exchanger	double-pipes	three-pipes	four-pipes
Ribbing's width, mm	80	147	164
Working pressure, bar	10 (optional till 16 bars)		

Technical characteristics of the QSK convectors are shown in Table 3.5. A standard length is 1250–3250 mm.

Table 3.5. Technical characteristics the QSK convectors

	QSK 260	QSK 320	QSK 410
Convector's width, mm	260	320	410
Convector's height, mm	110		
Stride parameter, mm	500		
Heat exchanger	four-pipes		

A four-pipe heat exchanger gives a possibility (if there is a cooling aggregate) to exercise a regime called "Cooling".

The main regimes of the QSK convectors are shown in Figure 3.18.

4. Heating and ventilation systems of the industrial premises

The building thermal regime is a set of factors and processes determining the heat environment in its premises. The feeling of thermal comfort, a normal course of production processes, the durability of building structures and technological equipment depend on a thermal regime.

A number of factors and processes that are closely related to each other influence the premises' heat environment:

– climate impacts;
– thermo technical and thermo physical properties of wailings;
– processes of the heat and moisture exchange in the premises;
– systems of the building's engineering equipment and means of their regulation.

The combination of these factors and their impacts on a human or animal organism may be various.

Ventilation is an indoor air exchange to eliminate the excesses of heat, moisture and other harmful substances in order to provide the acceptable parameters of microclimate and air cleanliness in a working or serviced area.

A serviced area (living area) is the space in the room limited by planes parallel to the floor and walls: at a height of 0,1 to 2 meters above the floor's level, at a distance of 0,5 m from the inner surfaces of the exterior and interior walls, windows and heating devices. A working area is the space in the room limited at a height of 2 m above the floor where a number of employees work.

Moisture, carbon dioxide, and excessive heat are principal harmful emissions formed in livestock buildings. Their amount depends on species, age, weight and a number of animals, as well as an indoor air temperature.

The ventilation system is a complex of the interrelated technical elements and devices used for treatment, transportation, supply and air removal.

According to the intended purposes ventilation can be divided into plenum, exhaust and plenum-exhaust.

Plenum ventilation systems are intended for a clean atmospheric air supply into the premises, and exhaust ventilation systems are intended for contaminated air removal from the premises. Plenum-exhaust systems ensure simultaneous clean air supply and contaminated air removal.

Depending on the method of the air exchange organization it's possible to single out general exchange, local and compound ventilation systems.

The general exchange ventilation exercises an air exchange in the whole airspace of the premises. At the same time harmful substances are diluted to the maximum allowable concentrations, and the excesses of heat and moisture are absorbed with clean air.

The local ventilation ensures air supply to a specific part of the premises or its direct removal from the processing equipment, which is a source of harmful emissions. The local ventilation systems achieve a maximum effect with a minimum amount of air, but their installation is not always possible.

The compound ventilation systems are the combinations of the general exchange ventilation with local.

According to the design there are channel and channel-free ventilation systems. In the channel systems the air moves through a branching network of channels, and in the channel-free systems – ventilation is carried out through the openings in the external wallings.

Depending on how the air is induced there are the ventilation systems with natural and artificial inducement. In the systems with natural inducement the air moves under the influence of natural forces – gravitational and wind pressure. Natural ventilation can be disorganized and organized. The disorganized ventilation is conditioned with the air filtration through the exterior wallings. The organized ventilation (aeration) is carried out due to specially provided adjustable openings in the outer protection enclosures. In the artificial inducement systems the air moves with the ventilator's help.

An air exchange is a partial or complete replacement of the indoor contaminated air with the clean atmospheric air. The rated air exchange must ensure the normalized microclimate's parameters and air cleanliness in serviced or working areas of the premises throughout the year.

In the agroindustrial complex the air heating systems with an artificial circulation and concentrated air supply in several locations and the air heating systems with an artificial circulation and a dispersed air delivery by means of the air conduits are used.

To ensure the air regime parameters of the industrial premises of the agroindustrial complex the following is used:

– ventilation towers (plenum and exhaust);
– ventilation plenum shafts;
– ventilation plenum valves ("vents") and air valves;
– axial ventilators;
– centrifugal ventilators;
– roof ventilators;
– ceiling ventilators (destratificators);
– plenum-exhaust installations;
– air humidifiers;

– the specialized packaged ventilating equipment (such as “Climate”).

Ventilation towers are designed to deliver fresh air to the premises mostly in a transitional and warm period of the year. They are the cylindrical vertically installed air conduits with two-speed ventilators. There is a sparger aerator on the bottom part of the tower that delivers air to the premises’ working area with horizontal jets; besides there is an automatic control system that is a box to regulate simultaneously rotation frequency of the ventilator’s motors of the several ventilation towers.

Technical characteristics of the ventilation KPS towers are illustrated in Table. 4.1.

Table 4.1. The KPS ventilation towers

Parameters’ name	KPS 108.21.08 (KPS 108.21.09)
Maximum air delivery, m^3/h	4000/8000
Ventilator (TU 105-7-154-83)	PSA 5.U3.000.PS
Electric motor installed capacity, kW	0,18/0,55
Electric motor (TU 16-525.593-85)	4AMPA80-A8/4U2
Synchronous frequency, r/min	750/1500
Inner diameter, mm	509
Ventilator’s rotation frequency with a maximuim supply, r/min	697,5/1410
Ventilator’s efficiency coefficient	0,67
Overall dimensions, mm	1004×1004×3100
Weight, kg	86,5 (73,8)

Figure 4.1. The VPT/VET

The ventilation plenum towers (VPT) and the ventilation exhaust towers (VET) (Figure 4.1) are designed to provide fresh air supply or contaminated (used) air exhaust respectively in livestock, poultry and other premises. They consist of a hood (aluminic composite material – ACM), a housing (galvanized steel or GS), a back valve “butterfly” (GS), a ventilator and deflector (GS). The towers can be lengthened at the expense of their own extenders. The main technical characteristics are presented in Table 4.2.

The ventilation plenum combined tower (VPCT) consists of a housing (galvanized steel), a hood, a deflector, and an air damper (all – GS) with an electric drive.

Additionally, it can be assembled with fresh air and mixing ventilators. A mixing ventilator is designed to mix up cold plenum air with warm air, existing in the premises. The VPCT operates together with the exhaust towers or exhaust ventilators and they are especially effective in small premises. The VPCT overall dimensions are similar to the VPT dimensions.

The ventilation shaft VPS-PE and VPS-Zn have become widely used for the ventilation systems in the industrial premises of the agro industrial complex (cattle-breeding, poultry).

The ventilation plenum shaft VPS-PE consists of a housing, a cylindrical or a bearing plate. There is the installed hood with a gassing fencing on the top of the tower, made of galvanized steel.

Table 4.2. Technical parameters of the ventilation towers

Type of a tower	Engine capacity, kW	Rotation frequency, min^{-1}	Productivity, m^3/hr	Diameter, mm
VET/VPT-4,0	0,16	1430	4200	400/480
VET/VPT-4,5	0,25	1400	5700	450/530
VET/VPT-5,6	0,37	1000	6000	560/640
VET/VPT-6,3	0,37	1000	9000	630/700
VET/VPT-7,1	0,37	1000	11000	710/796
VET/VPT-8,0	0,55	1000	17500	800/880

On the bottom part of the tower there is a circular air terminal unit, equipped with a linear electric drive, that conveys a flap along the tower’s axes and helps regulate the amount of the delivered air. The bearing plate is welded onto the tower’s housing and has the flat plate’s shape. The bearing plate’s installation angle is determined depending on the roof slope.

The amount of the air passing through the shaft depends on the draft intensity created with the exhaust ventilation towers and their productivity. Technical characteristics are presented in Table 4.3.

Table 4.3. Technical characteristics of the ventilation plenum shafts VPS-PE

Type of a shaft	Air delivery, m^3/hr	Diameter, mm	Weight, kg
VPS –01PE	3500	470	45
VPS –02PE	4300	520	50
VPS –03PE	6700	650	55
VPS –04PE	8600	730	60
VPS –05PE	11100	830	70
VPS –06PE	14000	930	75

The ventilation plenum shaft VPS-Zn consists of a hood and housing with a heat insulating layer that has a rectangular cross section; a bearing plate; a plenum ventilation valve (pane). The valve's housing is vinyl, joints made of stainless steel; other elements are made of galvanized steel. The bearing plate's inclination angle is determined depending on the roof slope. Technical characteristics are presented in Table 4.4.

Table 4.4. Technical characteristics of the ventilation plenum shafts VPS-Zn

Type of a shaft	Air delivery, m^3/hr	Width, mm	Weight, kg
VPS–01Zn	4300	1100	110
VPS–02Zn	4900	1250	116

To ensure a direct air flows' distribution in the livestock and poultry premises, various plenum ventilation valves ("pane") are used, the housing of which is made of polyvinyl chloride, and has a reliable thermal insulation and stainless steel hinge elements. They are equipped with a visor from precipitation and protective mesh netting. The overall dimensions are 30×1170 mm and 230×990 mm. Plenum panes are used for a uniform air flows' distribution in a ventilating room. The climate control system of a poultry-house "Climate 2000" can control an air flow into the poultry-house by changing the angle of the pane's opening (through the ropes and blocks system).

The air-valves (Figure 4.2) are used to smoothly regulate the air consumption in the ventilation systems and air conditioning. The air-valves are designed for air missing or non-explosive air mixtures, without adhesive and fibrous materials with temperatures ranging from –400 ºC to +700 ºC. The air-valves are designed to operate at the pressure grup up to 1800 Pa without deformation at the flaps' length of 1 m. The maximum permissible air velocity is 15 m/s.

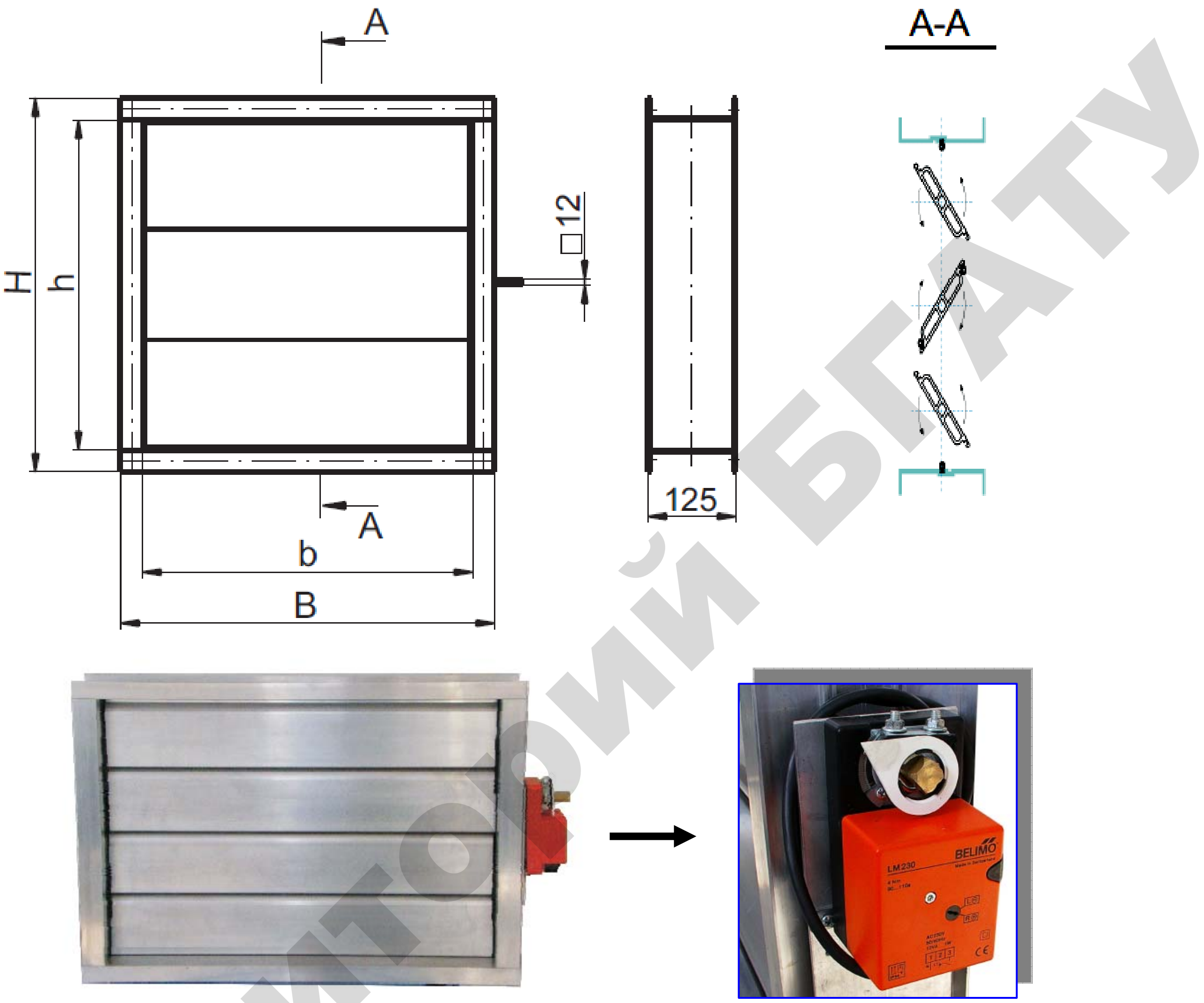


Figure 4.2. The air-valves (AVh and AVe)

The air-valve consists of an aluminum housing, aluminum turning vanes, seals, gears and drive (manual or electric). The housing and turning vanes are made of anodized aluminum profile, sealing of profile rubber, gears and bearing bushes made of nylon. The sealing of the blades at the junctions is provided with profiled rubber embedded in the blade. The blades' face seal with the housing is provided with the labyrinth abutment.

The valves are produced of two types: AVh – the air valve with a hand drive, and AVe – the air valve with an electric drive. Technical characteristics of the air valves are presented in Table 4.5.

Table 4.5. Technical characteristics of air valves

Type of a valve	Dimensions				Type of a drive	Weight, kg
	B	*H*	*b*	*h*		
AV 1400×1500	1480	1592	1400	1512	SM24, SM230	31,88
AV 1400×1900	1480	1992	1400	1912	SM24, SM230	39,56
AV 1400×2400	1480	2492	1400	2412	SM24, SM230	49,16
AV 1600×1200	1680	1292	1600	1212	SM24, SM230	33,76
AV 1600×1600	1680	1692	1600	1612	SM24, SM230	43,84
AV 1800×1600	1880	1692	1800	1612	SM24, SM230	47,48
AV 2000×1600	2080	1692	2000	1612	SM24, SM230	51,12
AV 2000×2000	2080	2092	2000	2012	GM24	62,8

Different types of axial ventilators are used in the agroindustrial complex, but the most widespread are low-pressure ventilators: AV–10–360, AV–12–380, AV–06–300; AW/AR 200—1000 (Figure 4.3, Table 4.6) and medium-pressure ventilators: AV–17–220, AV–20–197 and AXC (Table 4.7).

The ventilators AV–06–300 have air capacity in the range of 2–70 thous. m^3/h; when the drive's electric capacity is 0,12–15 kW.

As a rule the axial ventilators are low-pressure with the blades' amount of 4 or 6 pieces. The ventilators' structural elements are made of the ordinary quality steel; the blades of a rotor wheel are made of aluminum or steel alloys; the coating of the ventilators' elements is paint-and-lacquer or polymeric.

The purpose is ventilation of industrial, public and agricultural buildings. The operating conditions: the ambient temperature is from –40 °C to +40 °C.

The axial ventilators AV–10–410–12,5 combined with an air valve are used in poultry houses. The ventilator's housing and diffuser are made of galvanized steel, and a rotor wheel is made of polypropylene reinforced with fiberglass. The ventilator's air valve is made of aluminum or alloys and can be equipped with a hand or electric drive, which provides the blades' automatic opening and closing when turning on or off the ventilator. It ensures the complete hermiticity with the closed valve's blades and allows not using additional hermiticity and opening insulation in winter.

The ventilators' air delivery is 44–50 000 m^3/h, the motor drive's capacity is 1,5 kW, and the ventilators' weight is 120 kg.

Figure 4.3. Axial low-pressure ventilators:
1 — AV–10—360; 2 — AV–12—380; 3 — AW/AR 500 and 560

Table 4.6. Technical characteristics of the axial low-pressure ventilators

Name of parameters	Ventilator					
	AW/AR–400	AW/AR–450	AW/AR–500	AW/AR–560	AW/AR–630	AW/AR–710
Air consumption, m^3/h	4200	7380	9000	13400	17800	17000
Capacity, kW	0,16	0,6	0,78	1,4	0,6	0,9
Wight, kg	7,9	7,9	15,8	27	19	32

Name of parameters	Ventilator					
	AV–10–360–5,6	AV–10–360–6,3	AV–10–360–7,1	AV–12–380–5,6	AV–12–380–6,3	AV–12–380–7,1
Air consumption, m^3/h	8300	12000	11500	9000	15000	12700
Capacity, kW	0,37	0,75	0,37	0,37	1,1	0,37
Wight, kg	28	36	37	24	42	39

Table 4.7. Technical characteristics of the axial medium-pressure ventilators

Name of parameters	Ventilator				
	AV–17–220–8–01	AV–17–220–8–04	AV–20–197–8–01	AV–20–197–8–03	AXC–1250–6
Air consumption, m^3/h	18000	24000	18000	20000	95000
Capacity, kW	3,0	7,5	7,5	4,0	37
Wight, kg	130	150	170	130	600

In summer in the cattle keeping premises of dairy herd the axial ventilators of different types are used for the inside air cooling. The air capacity of these ventilators is 5–50 thous. m^3/h (the driver's capacity is 0,25–1,5 kW) and they are fixed in the upper part of the room.

Roof ventilators are also used in the agroindustrial complex; they are designed for operation without ductworks. Under an optimal operation regime when the performance is more than the minimum, ventilators can work with ductworks. Home-made roof ventilators VR and KC are the most widespread. The VK ventilators (Figure 4.4) of a single inlet, low pressure, have the backward-curved blades made of carbon steel. The ventilators are designed to be used in moderate climates at the ambient temperatures from –40 till +45 ºC. The VR ventilator's key features are presented in Table 4.8.

Table 4.8. Technical characteristics of the VR ventilators

Characteristics	Ventilator's index				
	VR 4	VR 5	VR 5	VR 8	VR 12,5
Electric motor capacity, kW	0,37	0,75	2,2	3,0	4,0
Rotation frequency, r/min	920	920	950	700	395
Productive capacity, m^3/h	3990	7880	16500	20300	43700
Total pressure, pascal	167	266	466	335	340
Weight, kg	56,4	70,4	117,0	163,0	608,0

Figure 4.4. The VKR roof ventilator

The exhaust ventilation systems (the roof ventilators DVS, DHS and DVSI Figure 4.5) are used in aggressive environmental conditions. The DVS reliable operation – in the buildings for various purposes (for example, warehouses), the DHS – a cost-effective solution for industrial buildings with the contaminated exhaust air (for example, poultry-houses), the DVSI – used in administrative buildings and the housing stock with high requirements to a noise level. The housing and the rotor wheel of the ventilators are made of aluminum. The frame is made of galvanized steel with a protective powder coating. The DHS ventilators have horizontal air emission; the rest ventilators have vertical air emission.

The rotation speed change of the single-phase ventilators is carried out via a stepless thyristor regulation or a five-step transformer regulation (by switching). The speed regulation of two-speed and three-phase electric motors is carried out by changing a connection method (“star” / “triangle”) or by using a five-step transformer. The ventilators are mounted on the roof curb.

The main technical ventilators’ characteristics are presented in Table 4.9.

Table 4.9. Technical characteristics of the DVS, DHS и DVSI ventilators

Characteristics	Ventilators					
	450E4	450DV	499DV	500DV	560DV	630DV
Quality of phases	1	3	3	3	3	3
Power consumption, kW	0,77	0,75	0,9	1,19	1,9	3,9
Rotation frequency, min^{-1}	1260	1260	1200	1325	1210	1400
Air consumption, m^3/h	5700	5500	6600	7900	10500	14200
Weight, kg	47	38	50	52	70	99

Figure 4.5. The DVS, DHC and DVSI roof ventilators

Nowadays the arrangement of the ventilation systems in industrial cattle keeping premises of pigs and poultry is different from the classical systems, which had been used in the mentioned above premises before 2000.

At an average (normalized) ambient temperature varying from –15 to +25 °C, the ventilation system is natural ventilation without the incoming air heating. However, in a cold period of the year the cattle keeping premises must have the corresponding design features taking into account “drain effect” preventing drafts and related to these sudden changes in temperature (Figure 4.6).

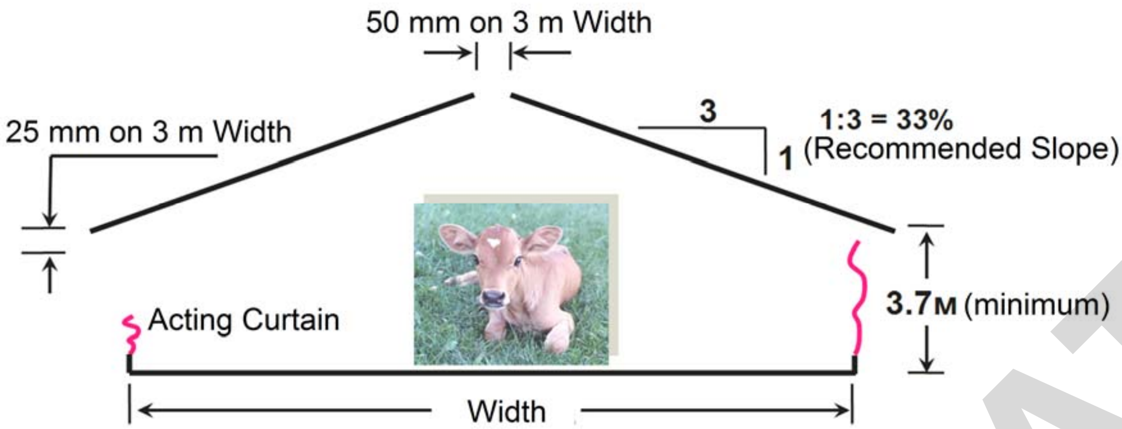


Figure 4.6. A typical construction for cattle keeping

The essence of the "drain effect" used in the design and construction of the ventilation systems in the livestock and poultry premises is as follows: the warmer inside air rises in the premises (a chimbley) and accumulates at the top or goes away through the open windows, ventilation and other leakages. The rising warm air reduces pressure at the building's base capturing the cold air through open doors, windows or through other forms of possible leakages. The maximum efficiency of "drain effect" is achieved during the heating season at a minimum temperature of the outside air.

When the outside air temperature reaches "extreme" values to –30 °C (in a cold period) a local heating of the indoor air is required, +35 °C (in a warm period), or it is necessary to use additional ventilation (starting ventilators, for example, YWF4E 450 Weather-vane, Figure 4.7), as well as the indoor air humidification (Figure 4.8). In industrial premises for cattle keeping (adult stock), ventilators with air productive capacity of up to 34000 m^3/h are used.

In the cow-houses a modern ventilation system must consist of a plenum ventilation device or natural (artificial) extract ventilation. There are four main options for ventilation systems:

– option 1: the system is based on the implementation of air circulation. The inflow of air masses is carried out through the roof shafts and extract ventilation is done with the help of roof ventilators.

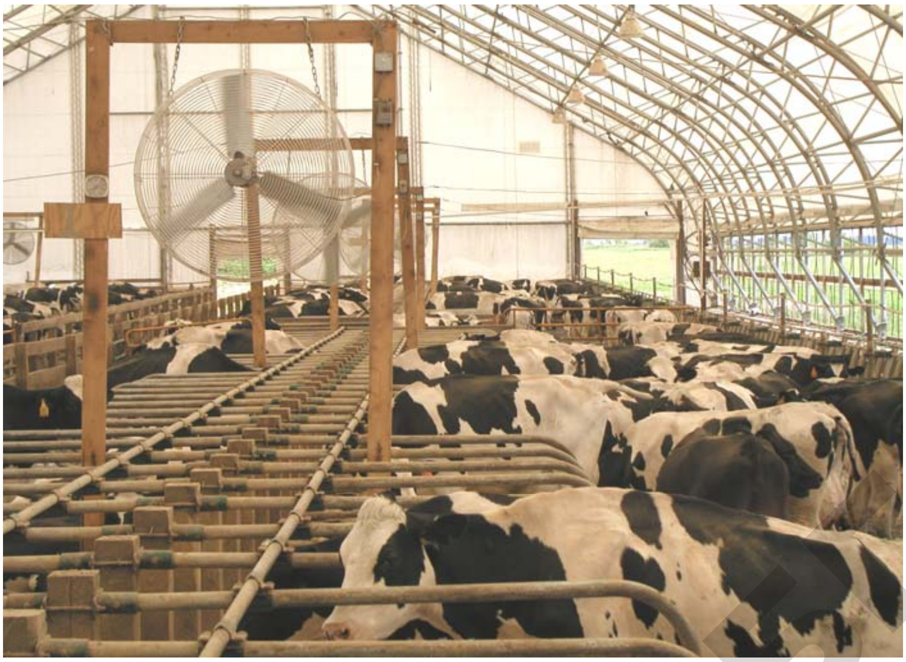


Figure 4.7. Starting ventilators' installation in the cattle keeping premises

Figure 4.8. Inside air humidification of a cow-house in a warm period

– option 2: the system implies that an air flow passes through a perforated ceiling, and extract ventilation is carried out through manure channels.

– option 3: the system consists of window frames, through which an air flow passes, and extract ventilation is carried out through roof ventilators. It may include additional wall ventilators.

– option 4: the system is suitable for hot regions, it allows humidifying the incoming air via nozzles above small windows.

The natural extract ventilation takes place through roof coverings or through window openings (Figure 4.9) ensuring an optimum air flow. The artificial ventilation is mechanical ventilation, may be exercised through channels of manure elimination. It is important to monitor that the air should circulate evenly throughout all animals' containers.

Figure 4.9. Natural ventilation through an air curtain

More often for the hangars' ventilation for cattle keeping, a ventilation design with air supply through two parallel ductworks is used, which is inserted into a ceiling part (classical design). This ensures a uniform delivery of air masses and the ambient air is supplied from an inflow chamber.

It should be remembered that each cow-house's ventilation draft is drawn up individually and takes into account the region's climatic characteristics and animals' age.

Membranes IsoCell (Figure 4.10) are used as curtains in modern constructions of the cattle keeping premises, their main advantages are the following:

– an insulating and full pressure system, which allows reducing heat losses and eliminate the risk of a building's frost penetration;
– a safe system (there is no winding mechanisms that can result in serious injury);
– provide plenty of light in the premises;

– provide a very large influx of fresh air;
– significantly reduce the energy consumption;
– provide more comfortable conditions for animals' keeping and for employees;
– an excellent high-quality and aesthetic system;
– a system with a low noise level.

The membranes comprise a plurality of the W-shaped air chambers. The chambers isolate the membrane's internal cells from the outside cells, and by doing it they do not admit cold air into the premises. First of all, such membranes are used as dividing walls in agriculture, where it is required to supply large amounts of fresh air.

Figure 4.10. Special membranes' usage instead of ordinary curtains in the cattle keeping premises

The main thermotechnical characteristics of the used membranes instead of curtains are presented in Table 4.11.

Table 4.11. The isolation coefficient for different types of walls

Characteristics	Membrane Polytherm	Square membrane	Membrane IsoCell
Termal resistance, $m^2 \cdot kW$	0,28	0,29	0,53
Teat transfer coefficient, $W/(m^2 \cdot k)$	3,54	3,44	1,90

The ventilation system of a poultry-house creates the temperature-humidity parameters of the poultry-house. These microclimate parameters are specific to different types and a period of birds' life.

The main types of the poultry-house ventilation are the following (Figure 4.11):
– vertical ventilation – the air exhaust is made through the vent holes in the roof of the poultry-house. The outside air passes through the plenum valves on both sides of the poultry-house;
– cross ventilation – the air exhaust is made with ventilators located on one side of the building. The outside air enters the valve located on the opposite side of the poultry-house. The system is equipped with an adjusting mechanism, and allows changing the speed of the ventilators' rotation;
– longitudinal ventilation – based on the principle of the cross ventilation system, but the movement of air masses occurs along the premises, because the ventilators are installed on the front wall;
– tunnel ventilation – built on the principle of longitudinal ventilation, except that the incoming air passes with the ventilating louvers' assistance, which are mounted on the opposite side from the ventilators. This creates a "tunnel effect".

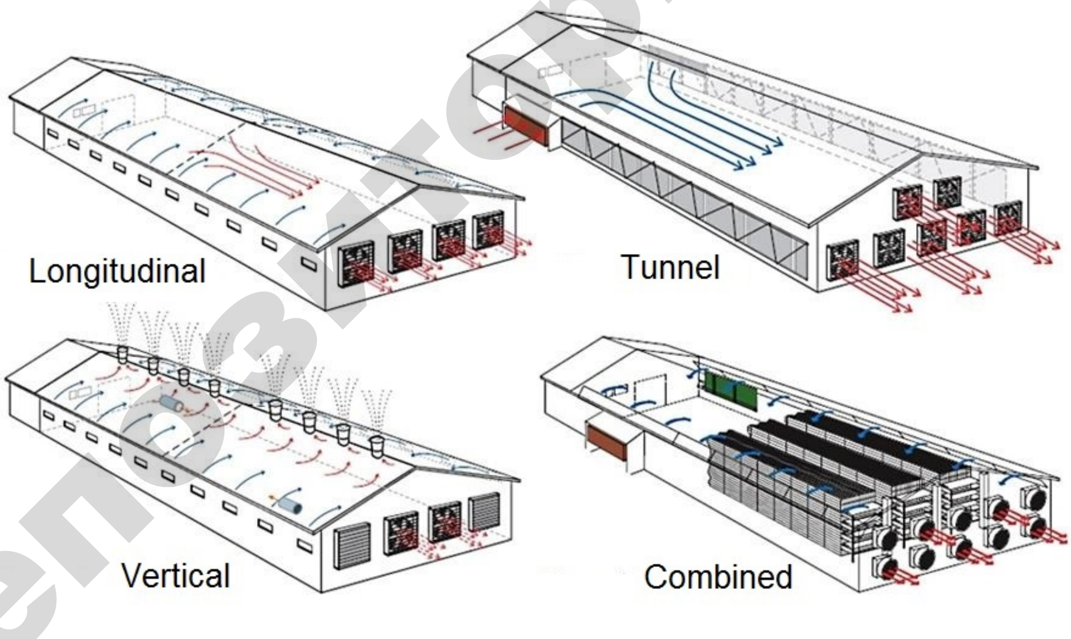


Figure 4.11. Modern typical designs of the ventilation installation in the poultry-house

There are some peculiarities of the premises' ventilation under different weather conditions. For example, in winter it is advisable to use the ventilation system with a slight air exchange, and in a hot season it is recommended to use the combined ventilation: tunnel combined with cross ventilation. In addition to it, during the chickens' growth, ventilation is usually not used during the first three days, and the air is humidified to the desired value.

When poultry is kept in cages it's optimal to use tunnel ventilation, which avoids air stagnation. Usually the increased performance ventilators are used for the poultry-houses, and the air flow valves are fitted with an electric drive, as a result it's possible to control the speed of the air masses movement.

To heat the premises gas heaters with the capacity from 30 to 250 kW are used in the majority of poultry farms. When suspended gas heaters are used, especially for large extended poultry-houses, it's recommended to install the so-called starting ventilators OVR–4,0 (4500 m^3/h), a high performance of which guarantees a minimum temperature drop in the whole premises.

Figure 4.12. General layout of gas heaters for the poultry-house

It should be noted that gas heaters (heat generators on natural gas) reduce the air dustiness by 60 %, the heating costs with the use of boiler-plants – in 3 times.

The recommended types of gas and diesel heaters and their technical characteristics are listed in Table 4.12, Figure 4.12.

Table 4.12. Technical characteristics of heat generators for poultry-houses

Parameters	Home-made		Foreign			
	VHC–90	VG–007	G–P75	GP–90	AGA–U1	TAS–800
Heat producing capability, kW	90	70	70	90	105	95
Capacity, kW	0,4	0,7	0,65	0,85	0,7	0,75
Gas consumption, m^3/h	8,2	7,0	6,5	9,3	9,0	–
Diesel consumption, l	5,4	–	5,4	6,4	7,5	9,5
Air delivery, m^3/h	5000	4000	5000	6500	7000	7000
Weight, kg	50	40	36	48	84	81

Generally, the starting ventilators’ air capacity is up to 5000 m^3/h. Primarily this is due to the permissible values of the air movement speed in the area of microclimate parameters’ maintenance.

Ventilation of pig complexes can be of several types.

Roof ventilation is the most energy-efficient form of ventilation that uses the wind’s force. Ventilation is carried out at the expense of plenum valves located on both sides, and a roof ridge, without the ventilators’ usage (Figure 4.13).

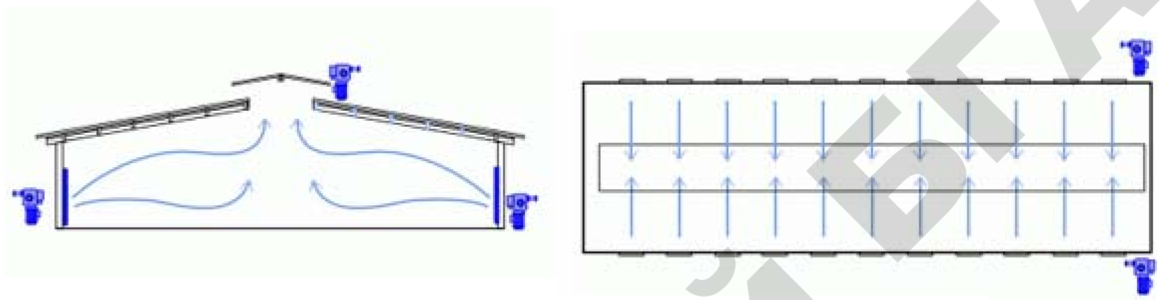


Figure 4.13. Roof ventilation system of pig complexes

Cross ventilation operates on the basis of natural ventilation, using the wind’s force (direction and speed), the ventilators are turned off, and it saves electricity. When saving energy and the desirable microclimate’s parameters are not preserved, there is a possibility of using forced ventilation by closing the windows from ventilators’ side and by connecting the side ventilators that accelerate their speed in accordance with the incoming air (Figure 4.14).

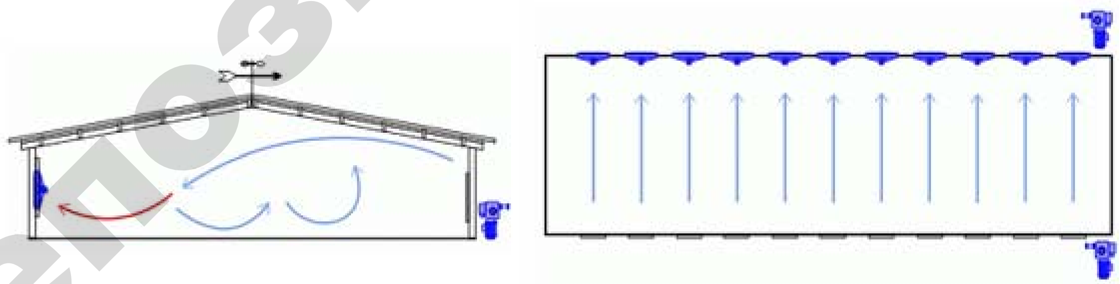


Figure 4.14. Cross ventilation system of pig complexes

Cross and combined ventilation operates on the basis of natural ventilation, using the wind’s force. When saving energy and the desirable microclimate’s parameters are not preserved, there is a possibility of using forced ventilation. The curtain from the ventilators' side closes and the side ventilators of low capacity are connected. If necessary, high capacity ventilators are connected.

Roof diffuse operates on the basis of natural ventilation, using the wind's force. When saving energy and the desirable microclimate parameters are not achieved, there is a possibility of using the forced ventilation by installing the side windows in a necessary position, moving to operation of the exhaust shafts (Figure 4.15).

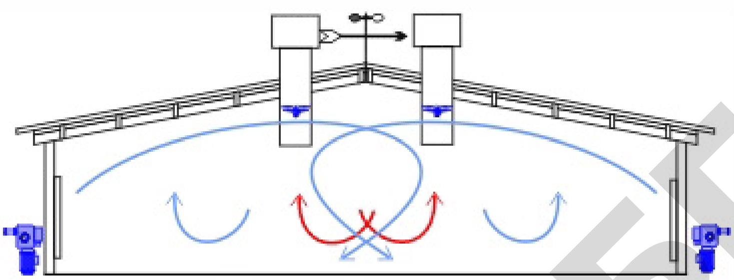


Figure 4.15. Roof diffuse ventilation system of pig complexes

Tunneling ventilation operates on the basis of natural ventilation. When saving energy and the desirable microclimate's parameters are not achieved, there is a possibility of using a forced regime "tunnel". In this case, all the side windows are closed and gradually high-powered ventilators are being turned on, reaching an optimal cooling due to the emerging air flow in the whole premises (Figure 4.16).

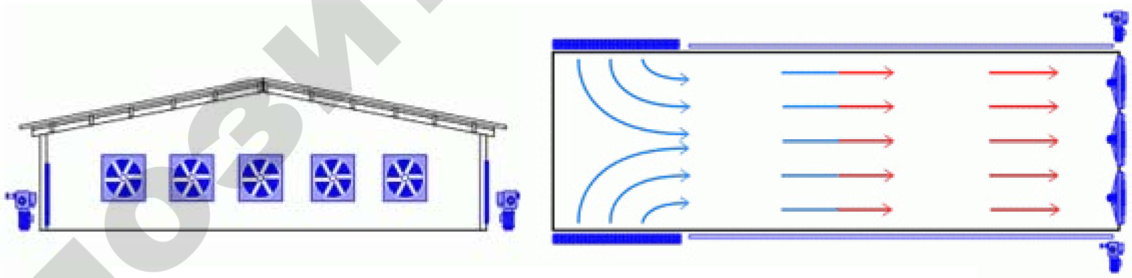


Figure 4.16. Tunneling ventilation system of pig complexes

While selecting a ventilation type, in addition to the volume of the incoming air, it is necessary to take into account its circulation in the premises and correspondingly the wind's speed in the areas of animal husbandry. This index should not exceed 0,1 m/s – in winter, and 0,2 m/s – in summer. At the air temperature of above 22 ºC the wind's speed should be increased up to 0,5–1,0 m/s.

In addition, all the ventilation systems can be divided into three groups:

– systems with overpressure (air is heated in pig complexes);
– systems with underpressure (air is sucked from pig complexes);
– systems with balanced pressure (air is heated and sucked simultaneously).

In the premises for pig husbandry (as in the poultry-houses' premises) plenum valves are used (small windows).

In summer – a valve's window must be opened by more than 57 %. The two directions of air flow, which enter the premises, create a microclimate according to the set parameters (Figure 4.17).

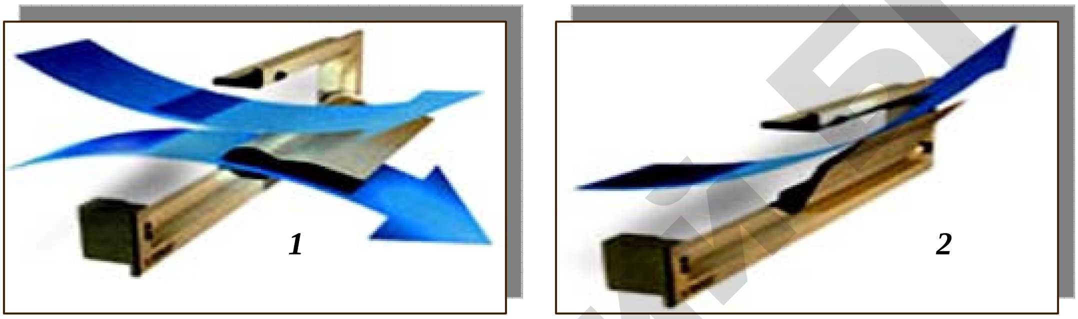


Figure 4.17. The plenum valves' operation in summer (1) and in winter (2)

In winter – a valve's window must be opened by less than 57 %. A single air flow is formed and enters the upper part of the pig complex in such a way that animals (birds) are maximally protected from overcooling and blowing.

The problem of energy-efficiency while heating and ventilation in the agroindustrial complex can be solved in three directions:
– through the use of renewable energy sources (solar, wind, biogas);
– through the use of secondary and energy resources (SER) of industrial enterprises, as well as the utilization of waste heat of farms and complexes;
– through the improvement of the buildings' thermal protection, the improvement of control and automation systems of the agricultural processes.

The typical ventilation systems involve the use of the waste-heat equipment in industrial premises of the processing industry of the agroindustrial complex

The improvement of the building's thermal insulation characteristics is an effective means to reduce heat losses in the premises, but it's not a decisive factor for the livestock premises, as a result thermal power peculiarities (consequences) of its application change. The other decisive factor of the livestock premises' thermal power is the fact that animals should be regarded as significant sources of heat and moisture.

The factors affecting the energy needs of the livestock premises can be divided into two groups:

<u>1st group</u>

The factors that change, regardless of a human's desires (there is no real possibility of their correction): the objective characteristics defined by the animals' type and age; the heat and moisture quality given by animals; the outdoor air temperature and its change in a particular geographical area.

<u>2nd group</u>

The factors that can be changed in the interest of a more efficient energy use for the heating purposes: the premises heat insulation; an air exchange and air distribution system in the premises; an indoor air temperature.

A lot of attention should be paid to heat losses reduction through the floor. According to the experiments the floor insulation with the help of the thermal resistance layer equals to 1–2 m^2·K/W, reduces the heat losses through the floor by 80–90 %.

An air exchange increase by 20–30 % in the livestock premises, with a constant total weight of animals and their livestock in terms of a heating period's duration, is equivalent to a two-time value reduction of the building's heat-insulating properties. This in its turn means that a heating period's duration, which is the main indicator of the annual energy costs of heating, can be reduced not due to the costly insulation equipment, but by means of the ventilation minimum level in winter or with a careful setting of the ventilation equipment, including heat recovery.

The main ways to improve the efficiency of the heating and ventilation systems (HVS) are the following:

– the HVS correct calculation taking into account the minimum air exchange standards, an inside air temperature, recommendations on thermal resistance of enclosures: $R_{\text{(walls and floors)}} > 3{,}2$ m^2·k/BW; $R_{\text{(enclosure)}} > 6{,}0$ m^2·k/W;

– a rational use of the modern HVS designs taking into account the type of animals (birds) and their keeping method;
– optimal arrangement of the distributing ductworks and plenum shafts in the industrial premises of the agroindustrial complex, as well as the special equipment arrangement (hot air curtains, plenum-exhaust and heat utilization installations);
– application of the HVS new technical solutions, including the local heating systems of the young stock.

It should be remembered that the heat utilization contained in the exhaust air provides up to 20 % of the heat-saving used to warm up the incoming air delivered into the premises.

The application of the air heating systems, where gas heaters and water-air heaters are used, has recently become very popular.

Gas heaters can be classified as it follows:
– *mixing gas heaters* (*direct air heating*). The thermal efficiency coefficient is about 100 %.
– *regenerative gas heaters (only for recirculating air operation).* The standard, typical equipment. The thermal efficiency coefficient of condensing air heaters is about 80 %.
– *regenerative gas and air heaters (with the ability to adjoin a ductwork or a mixing chamber)*. The ability to operate with plenum or recirculating air.

All heaters are characterized by low inertia, the absence of a chimney and an intermediate heat carrier (and, therefore, there is no leakage and defrost).

However, the use of gas heaters has certain peculiarities:
– *Light (high-intensity) radiants*. The recommended height of the heaters' placement is from 7 m, a maximum height is 15–17 m (and it is recommended for each meter of the heater's installation higher than 7 m to add 5 % of thermal capacity of the radiant heating system from the calculated, but not more than 25 %).
– *Dark (low-intensity) radiants.* The recommended height of the heaters' placement is from 4 m, a maximum height is 10–12 m (and it is recommended for each meter

of the heater's installation higher than 7 m to add 5 % of thermal capacity of the radiant heating system from the calculated, but not more than 25 %).

– *Superdark (strip) radiants.* The recommended height of the heaters' placement is from 4m, a maximum height is 25–30 m.

Water and air heaters (Figure 4.18) have a number of positive characteristics: fire safety; a wide range of the implementation variants (plenum, plenum-exhaust); the opportunity to use them not only for heating, but also for cooling. A free choice of energy sources (a boiler-house on gas, fuel oil, wood/pellets, electric or the use of a heat pump).

The water radiant ceiling panels: a recommended height of the heaters' placement is from 2,5 m, a maximum height is up to 40 m.

The electric air heaters: the simplicity of regulation and implementation, low capital costs. The absence of an intermediate heat carrier, and, therefore, there is no leakage and defrost.

The electrical infrared heaters: a recommended height of the heaters' placement is from 2,5 mm a maximum height is up to 10 m.

The optimum installation height of the air heaters with axial ventilators, placed directly in the premises (horizontal placement), is no more than 3–4 m. A maximum installation height of the standard air heaters and ceiling ventilators (destratificator) is up to 18 m, using the vertical installation with the vertical jets' air distribution.

Destratificators ensure a continuous air mixing in spaces of the large (bulky) premises that are used for industrial and commercial purposes. Their usage eliminates the temperature and moisture distortion at the premises' height; they reduce energy costs during the heating system exploitation (air conditioning).

Destratificators are mounted on the ceiling and controlled with the main panel equipped with a speed regulator. The speed of ventilation movement conforms to the hygiene standards and does not exceed 0,1 m/s. The horizontal air flow does not affect humans and does not lead to dust displacement and other light particles.

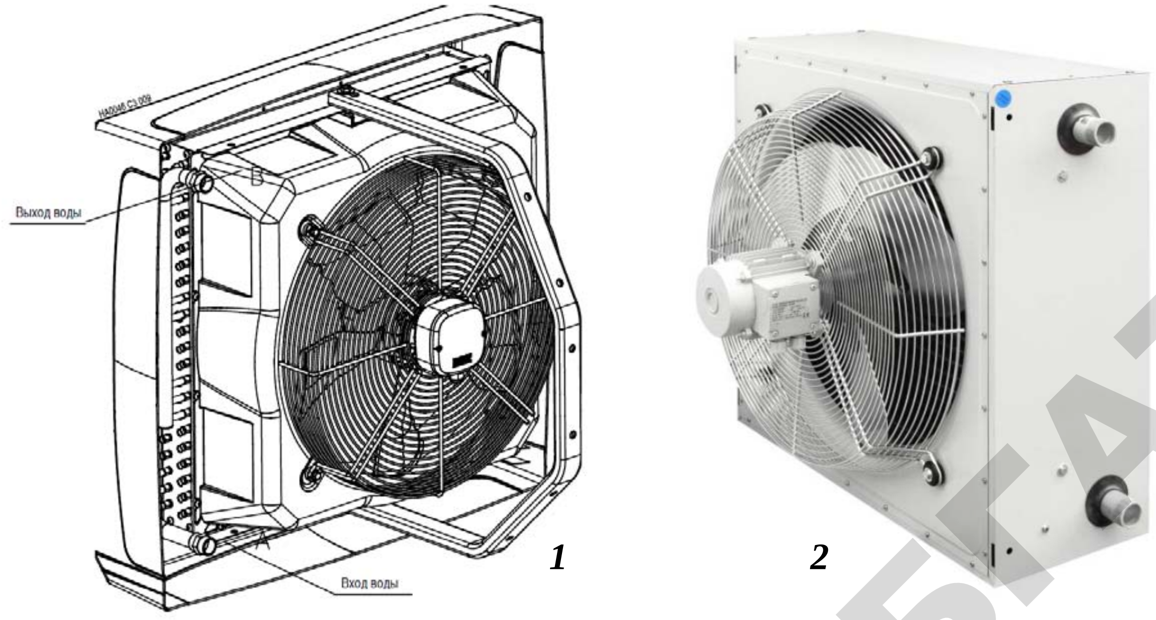


Figure 4.18. Water heaters of the air heating system, produced by ApenGroup: 1 – air-heating aggregate A30 aeromax line; 2 – air-heating aggregate Aqua without air jet diffusers

There are no fundamental limitations for the air heaters with the centrifugal ventilators (plenum installations) to organize the air intake under the ceiling (at any height) (except for capital expenditures).

In industrial premises of the agroindustrial complex (bakery plants, meat-processing plants, etc.), during a products' loading into machines to transport them to shops, the air curtains are widely used to avoid the cold (warm) air penetration into the premises.

An air flow "sealing" the doorway and also the device originating this flow is called an air curtain (Figure 4.19). The air curtains are used to separate zones with different temperatures on both sides of the opened openings of the operating windows, the entrance doors and gates.

A properly installed air curtain reduces heat losses by 90 % and improves thermal comfort in the premises. Apart from the obvious resources and energy conservation, the air curtains do not allow the penetration of drafts that lead to employees' diseases, preserve heat, and they make it feasible for shops to keep the doors open to attract customers in winter.

In summer, the air curtains can operate without the heating elements' activation, protecting the cooling premises from heat penetration and keeping the conditioned air protecting from dust and insects penetration.

Figure 4.19. Air curtains: 1 – aggregates AB Airbloc (Great Britain); 2 – aggregate ACR, Dutch company Winterwarm

Heat recovery of the exhaust air is a process of thermal energy re-use in the ventilation system. The heat of the exhaust ventilation air is a basic secondary energy resource of industrial, residential and public premises. Heat consumption for the ventilation air heating in the residential premises is 40–50 % of consumption for heating, in the industrial and public premises it reaches 40–80 %. In industrial buildings, except for the exhaust air heat, the exhausting gases of the heat-using equipment, boilers and etc. are referred to secondary and energy resources.

Different types of heat and utilization installations are used for heat recovery. Heat and utilization installations are the ventilation and heating installations that use the exhaust air heat of the premises (secondary heat resources, secondary energy resources) to heat the fresh incoming air. They are intended for ventilation of industrial, livestock and public premises. In this case, the secondary heat sources are considered to be the following:

– air heat removed with the systems of general ventilation, air conditioning and local exhausts;

– heat of liquid flows and gases from the processing installations.

The removing air's heat utilizers used in the air ventilation and conditioning are divided into four types:

– cross-flow and cross-current recuperative heat exchangers of plated type;
– regenerative heat exchangers with a rotating nozzle;
– heat exchangers-utilizers with an intermediate heat carrier;
– heat exchangers-utilizers with heat pipes.

Plenum-exhaust installations (PEI, Figure 4.20) are intended for the air exchange organization with heat recuperation in separate premises of various purposes (industrial, domestic, etc.). In a cold season, a recuperator reduces energy consumption to heat the incoming air up to 70 %, and in summer reduces the air conditioning costs.

Figure 4.20. Modern PEI LuftMeer

The PEI is an aggregate comprising a plenum-exhaust installation and located in the same housing. The PEIs have different configurations: they can be – roof, overhead, suspended, etc. Usually the installations are equipped with flexible insertions, air valves, and filters, mixing chambers, heaters, coolers and silencers.

The installations with heat recuperation purify, heat and deliver fresh air. They extract the heat from the outgoing air and transfer it to the incoming air. The installations have productive and noiseless ventilators, an electric heater. Thanks to an automation system it's possible to regulate an air flow and temperature of the delivered air.

As a rule the installations' switching on and operational control are exercised by means of a thyristor regulator of the engine' s turns that smoothly changes the ventilator's rotation speed in the range of 0–100 %.

Among the ventilating equipment, plenum-exhaust installations have a wide range of capacity from 0,3 up to 250 thous. m^3/h. The installations' heat-capacity (the heater's capacity) is in the range from 6 to 2300 kW; cooling capacity can reach 1000 kW.

Nowadays a series of modern installations "Climate" is the most popular ventilation equipment, combining the plenum-exhaust ventilation system and air conditioning in a compact heat-insulated housing made of galvanized steel with a built-in automation system.

Inside the installation in the isolated plenum-exhaust ducts there are two radial ventilators of a double intake, two cartridge filters, a block of a reversible heat pump, an electric (water) heater and automation system. A reversible heat pump is filled at the factory and it's a hermetic freon contour with the installed copper and aluminum plated heat exchangers in plenum-exhaust ducts.

When the installation operates in a cooling regime, the heat exchanger in a plenum duct is as an evaporator and cools the incoming air, and the heat exchanger-condenser is cooled with the removing air from the premises. In its turn, while operating under a heat-ing regime, the incoming outside air is heated with the heat exchanger, which in this particular operational regime performs the condenser's function, and the heat exchanger-evaporator, placed in the exhausting duct, absorbs the heat energy of the removing air. The main technical characteristics of the installations "Climate–035", "Climate–042" and "Climate–050" are presented in Table 4.13.

A plenum-exhaust multifunction ventilation installation "Climate" (Table 4.14) is designed to perform the following functions:

– fresh incoming air delivery to the served premises without recirculation (mixing up with the exhaust air);

– outgoing air removal from the served premises;

– supply air purification from dust and aerosols (depending on the used filters' class the filtration rate may be from EU–3 to EU–7);

– incoming air heating or cooling via a built-in reversible heat pump (regime "summer"), and the air heating via an electric heater (regime "winter").

Table 4.13. Technical characteristics of the PEI "Climate"

Characteristics	Installation's number		
	98, 108	97, 109	95, 120
Maximum air supply and intake, m^3/h	1200	3000	4000
Minimum air supply and intake, m^3/h	300	400	600
Capacity of air cooling (intake), kW	4	8	12
Capacity of air heating (intake), kW	4,2	8,4	12,6
Cooling capacity coefficient	2,9—3,3	2,9—3,3	3,0—3,5
Heat capacity coefficient	4,1—5,4	4,1—5,4	4,5—5,8
Weight,kg	95,5	203	249

Structurally the installation consists of three blocks. Inside the installation in the completely isolated plenum-exhaust ducts there are radial ventilators, filters, and a block of a reversible heat pump, electric heaters and automation system A reversible heat pump is filled at the factory and closed within the installation two freon contours with the installed copper and aluminum plated heat exchangers in plenum-exhaust ducks. When the installation operates in a cooling regime a heat exchanger in a plenum duck is as an evaporator and cools the incoming air, and the heat exchanger-condenser is cooled with the removing air from the premises.

Table 4.14. Technical characteristics of the PEI "Climate 7200" (model 111)

Characteristics	Value
Maximum air supply and intakea, m^3/h	7200
Minimum air supply and intakea (summer regime), m^3/h	5000
Minimum air supply and intake (winter regime), m^3/h	2800
Capacity of air cooling (intake), kW	30,0
Additional heating capacity of the incoming air, kW	112,0
Cooling capacity coefficient	3,3—4,2
Weight, kg	960

In all PEI "Climate" an automatic control system is used, which provides: an independent three-stage speed regulation of plenum-exhaust ventilators and an automatic regime switching "heating/cooling" according to the readings of temperature sensors and usage settings.

Figure 4.21. General design of ventilation aggregates with heat recovery, RIS HE 2000—5000

Modern ventilation aggregates with heat recovery are of particular interest (Figure 4.21 and 4.22, Table 4.15).

Table 4.15. Technical characteristics of the RIS ventilation aggregates with heat recovery

Characteristics	2000HE	3000HE	4000HE	5000HE
Air supply (intake), m^3/h	2000	3000	4000	5000
Ventilators' capacity, kW	1,5	2,5	2,2	3,0
Heater's capacity, kW	15	24	27	33
Weight, kg	328	395	500	570

Ventilation aggregates with heat recovery RIS HE 2000–5000 purify, heat and deliver fresh air. The installations extract heat from the outgoing air and transfer it to the incoming air. They are equipped with productive and noiseless ventilators (ventilators with a belt drive are used in some installations). Plastic heat exchangers used in the heat utilization installations have the heat transfer efficiency of 58–62 %, and the rotary heat exchangers of 74–75 %. The aggregates are intended for cleaning, heating and delivery of fresh air into the premises and they are only in the systems of clean air ventilation and conditioning.

Ventilation aggregates with heat recovery RIS HE 2000–5000 purify, heat up and deliver fresh air. The installations extract heat from the outgoing air and transfer it to the incoming air. They are equipped with productive and noiseless ventilators (in some installations ventilators with a belt drive are used). The heat transfer efficiency of plated heat exchangers used in the heat recovery units is 58–62 %, and the heat transfer efficiency of rotary heat exchangers is 74–75 %. Aggregates are used for cleaning, heating and supply of fresh air into the premises and only in the systems of ventilation and air-conditioning of clean air.

Systemair produces a wide range of ventilation aggregates with heat recovery (Figure 4.22). They can be successfully used in the ventilation systems for residential, commercial and industrial buildings.

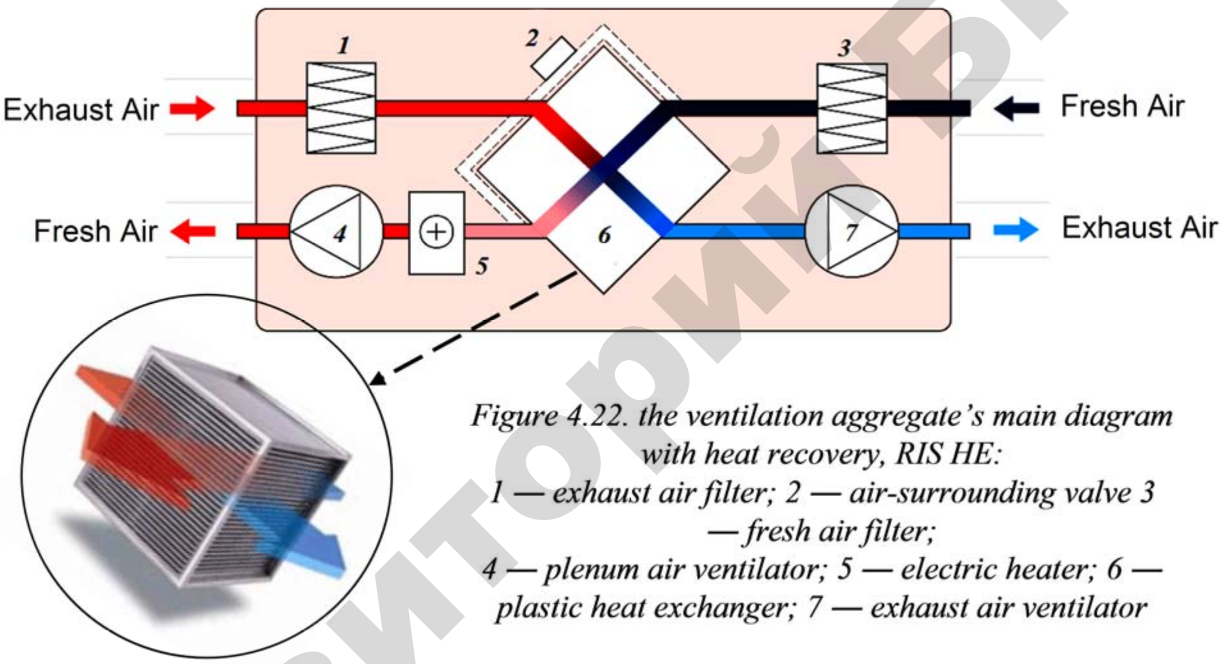


Figure 4.22. the ventilation aggregate's main diagram with heat recovery, RIS HE:
1 — exhaust air filter; 2 — air-surrounding valve 3 — fresh air filter;
4 — plenum air ventilator; 5 — electric heater; 6 — plastic heat exchanger; 7 — exhaust air ventilator

Ventilation aggregates with heat recovery Systemair are combined and characterized by the following features: the equipment's small dimensions allow using it in a limited space; the use of integrated and pre-configured sets of automation; the ability to control the ventilators' performance; high energy efficiency of plastic and rotary heat recovery boilers and a low noise level.

The heat utilization installations (Figure 4.23, Table 4.16 and 4.17) designed in the Republic of Belarus, are intended for heating and ventilation of the livestock and poultry premises using the exhaust air heat.

Table 4.16. Technical characteristics of the UT heat utilization installations

Characteristics	UT–5	UT–10	UT–15	UT–15B	UT–20
Air supply (intake), m^3/h	5400	9700	15200	15700	16700
Ventilators' capacity, kW	5,5	5,5	15,0	15,0	15,0
Free net pressure, pascal	800				
Weight, kg	1345	2060	2420	2560	2770

Table 4.17. Technical characteristics of the UT–F–12 heat utilization installations

Characteristics	Value
Air supply (intake), thous. m^3/h	12
Heat capacity (Δt = 40 °C), kW	64
A number of heat pipes, ps	200
Utilizer efficiency coefficient	0,5
Overall dimension, mm	3000×2500×1400
Weight, kg	2150

Figure 4.23. General view of the UT heat utilization installations

Structurally the installation is a plenum-exhaust ventilation aggregate. The installation's housing comprises an aluminum frame to which fixed or removable panels are attached; they are made of galvanized steel, the heat insulation thickness is 25 mm. Plenum-exhaust valves are fixed to the housing. To clean fresh air in the plenum duct, the following clean class air filters EU-3, or EU-4 are installed. A heat utilizator is a heat exchanger consisting of finned aluminum heat pipes.

The energy-saving diffusers of the incoming air – BOOSTER, mounted to the ceiling or high on the walls, are of particular interest for the industrial high-ceiling premises of the agroindustrial complex (bread factories, dairy plants, and meat-processing plants) (Figure 4.24). The air consumptions range is from 350 to 6500 m^3/h. BOOSTER is especially useful in the premises that require warmth at night and early in the morning and cold in the daytime. The upper part of the diffuser is equipped with unique aerodynamic discs Swegons, the lower part of the diffuser is equipped with the distribution system Varizon. Automation regulates the usage of the diffuser's upper and lower parts.

The floors' heating in animal husbandry has several advantages that contribute to the creation of optimal temperature regimes in a zone of animals' presence and their protection from the adverse effects of the environment during a cold season, a productive animal's growth and risk reduction of their disease.

Figure 4.24. Placement of the incoming air diffusers at a dairy plant

The heated floor is a system converting electric energy into heat energy due to the current's heating effect in the heating elements made in the form of special cables, or a system using the coolant's heat (hot water, steam, hot air) to heat the floor's mass.

Initially it's important for the animals' growth that the temperature of their bodies should not reduce because of an insufficient floor temperature. For example, for the pigs' growth during the first 2–3 days after their birth it is necessary to maintain the floor temperature at 30 °C. Then, within a month the floor temperature should drop to 3–4 °C per week, up to 17–18 °C.

As a rule electric energy is used as a tool for a local heating of young animals. It is converted into thermal energy directly in electric appliances. Such local heating tools are:

– electro-heated floors (Figure 4.25, 4.26);

– electro-panels;

– electro-floor coverings;

– infrared radiation (IR) applicators (Table 4.18);

– electro-brooders (Figure 6.6);

– combined heat installations and applicators (IKUF, IKUF-1M).

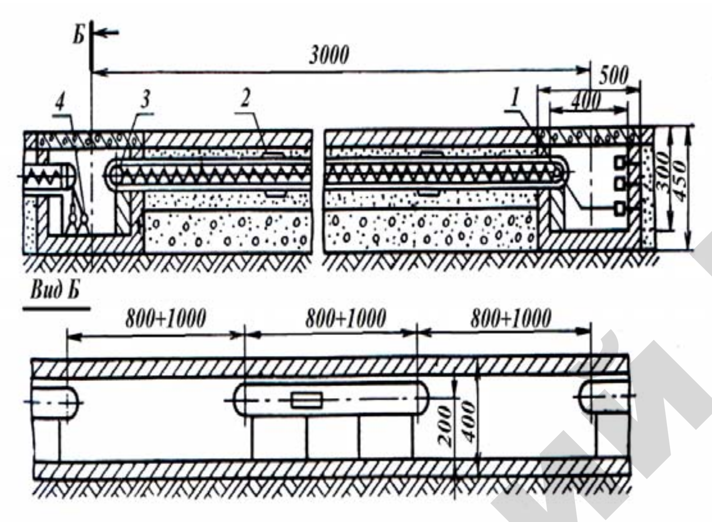


Figure 4.25. The electro-heated floor's installation with the heating elements in insulated pipes:
1 – heating coil of galvanized wire; 2 – concrete;
3 – insulated pipe; 4 – bus duct

Table 4.18. Technical characteristics of the infrared radiation applicators (IR) (U~220 W)

Equipment designation	Capacity, kW	Diameter, mm	Length, mm	Service life, h
IKZ 220-500	500	180	267	6000
IKZK 220-250	250	130	185	6000
IKZK 220-500-1	500	130	195	4000

In the selected floor's areas, where the installation of the electro-heated floor is required, a deepening is dug (0,3–0,6 m), the bottom of which is carefully compacted. Kerazmit and similar heat insulating materials except for boiler slags can be used as insulation. A protective mesh made of steel wire with a diameter of 3–4 mm, with a mesh size of 250x150 mm, which is securely connected to a neutral wire mesh. The width of the heated band depends on the animal type. In the cow-house the band with the width of 0,5–0,6 m is heated; in the sow-house – 1,3 m; in the poultry-floor house – 0,2–0,3 from the premise's width.

Bare steel conductors (when supplied at a reduced voltage of 30-60 V) and special solid conductors POSKHP, POSKHV, POSKHVT (suitable for connecting a phase voltage up to 220 V) and heating cables are used as the heating elements.

The length and sectional area of a heating element are conditioned, on the one hand, with the acceptable conductor's temperatures and the floor's surface, and on the other hand with its electric properties. It's necessary to take into account that steel conductors produced with manufacturing industry have a diameter of 1,8–5 mm and POSKHP and POSKHV – 1,1–3 mm (monolithic conductor) and section is 0,75–6 mm^2 (stranded conductor).

Conductors' technical characteristics are presented in Table 4.19.

There are resistive and self-regulating cables. A resistive cable is one or two thin metallic spiroid conductors enclosed in insulation. A single-line cable is connected at both ends. Two-line cables can be connected at one end, while at the second end conductors connected and isolated short. In many cases, the ability to connect at one end is an advantage, because it requires a less length of the connecting cables.

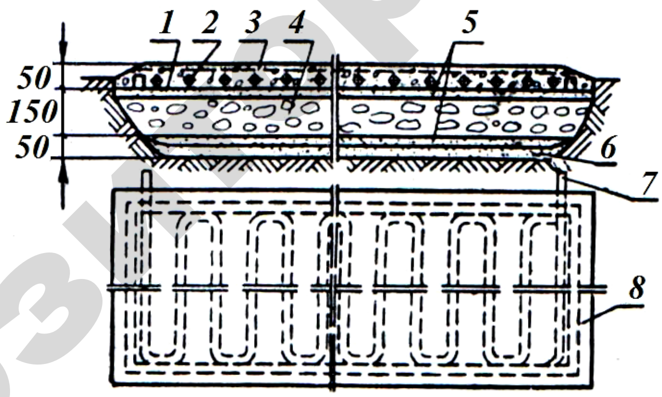


Figure 4.26. The electro-heated floor's device with a heating conductor:
1 – concrete; 2 – heating conductor; 3 – screen metal mesh;
4 – heat insulation; 5 – sand; 6 – hydro-fuge insulation; 7 – wire terminations;
8 – wood frame

The advantage is low cost, no inrush currents, and constant power over time.

The possibility of the cable's local overheating, cold zones' appearance while installing at the contour's beginning/end are the disadvantages.

Table 4.19. Technical characteristics of the heating conductors

Conductor	Insulation	Conductor's acceptable temperature, °C	Resistance at $t_{op.}$, Ohm/m	Maximum power-to-weight ratio, W/m
POSKHP	polyethylene	95	0,194	12-13
conductor	monolithic	diameter = 1,1; 1,2; 1,4; 1,8; 2,0; 3,0 mm		
	multiwire	section = 0,75; 1,0; 1,5; 2,5; 4,0; 6,0 mm^2		
POSKHV	polyvinyl chloride	70	0,174	9-10
conductor	monolithic	diameter = 1,1; 1,2; 1,4; 1,8; 2,0; 3,0 mm		
	multiwire	section = 0,75; 1,0; 1,5; 2,5; 4,0; 6,0 mm^2		
POSKHVT	polyethylene with polyvinylchloride sheath	95	0,174	10-12
conductor	monolithic	diameter = 1,1; 1,2; 1,4; 1,8; 2,0; 3,0 mm		
	multiwire	section = 0,75; 1,0; 1,5; 2,5; 4,0; 6,0 mm^2		
steel	no	300	0,15-0,02	20-30

A right choice of the length and cross section of a heating element is possible only due to a joint solution of electrotechnical and thermotechnical problems taking into consideration the operational efficiency at a temperature stipulated with technology (Table 4.20).

Table 4.20. Recommended parameters to calculate the electro-heated floors and panels

Animal type	Floor's recommended temperature, °C	Floor's surface capacity, W/m^2	Heater's line capacity, W/m^2	Recommended installation pitch, m
Chickens	35-40	150-300	7,5-30	0,05-0,1
Young pigs	25-30	100-200	7-20	0,1-0,15
Fattening pigs	18-20	80-150	12-30	0,15-0,2
Sick cows	26-29	150-190	22-40	0,15-0,2
Calves	20-24	100-150	10-22	0,1-0,15

5. Energy-saving technologies during the heating networks' operation

Heating networks are a crucial component of the total heat supply system, the main directions of which are defined in "the Concept of the heat supply development in the Republic of Belarus for the period till 2020" (approved by the decision of the Council of Ministers of the Republic of Belarus 18.02.2010 № 225, the National register of legal acts of the Republic of Belarus, February 22, 2010 N 5/31300). This document defines the hardware requirements, the questions concerning balance sheet attribution of the heating networks, the development of heating sources, tariff policy, and relations between the heat supplying organizations and consumers, control of the heating supply systems, a normative base, demonopolization and formation of market relations.

The heating networks' condition in the Republic of Belarus implies that it is necessary to solve the problems of energy-saving and resource-saving. This means using fundamentally new technological and energy-efficient engineering systems in construction and modernization of the heating networks, especially in rural areas. Currently, the existing heating networks[3] are characterized by a high degree of wear. About 25 % of the heating networks have exceeded the standard lifetime (30 years). This problem must be urgently solved; otherwise the situation can become catastrophic.

In order to specificate the concept's general provisions for the heat supply development it's essential to focus on the following directions of the heating networks' development:

– heating networks' construction in the underlaying with the usage of pre-insulated pipes;

– heating networks' construction in the above-ground laying with high-effective thermal insulation;

– building equipment with the individual heating units according to an independent scheme (if technically possible and a heat carrier's temperature parameters are provided), equipped with automatic control means and metering of heat consumption;

– development of the existing automated systems of industrial processes' control of the heating networks and design of new systems.

The fixed production assets' updating, connection of new consumers in accordance with the pace of housing construction, acceptance of additional heat loads from the housing and utility organizations and industrial users require an annual

[3] *The total length of the heating networks at the beginning of 2014 amounted to 5,7 thous. km, with average losses of thermal energy amounted to 9,55 % [40].*

replacement of 100–120 km of pipelines (in a single-pine depreciation) in the system of State Production Association (SPA) "Belenergo" and 550–660 km in the housing and utility services.

Belarus is a country with a high level of district heat supply with a prevailing method of heating networks' laying in the form of laying in crawlways with the mineral-cotton insulation. Hydration of the used materials in operation drastically reduces the heat-insulating properties of the heat-insulating constructions, which leads to non-productive heat losses exceeding normalized. It should be remembered that non-productive heat losses – losses due to poor technical conditions of the heat-recovery equipment and heating networks, or an unsatisfactory organization of their operation. Heat energy normalized losses – a sum of normalized losses of heat energy through the pipelines' insulation and a heat carrier's leakage from the heating networks.

The basic condition for the proper heating systems' functioning is to provide available pressure in the heating networks, over heat supply stations of consumers, which is sufficient for the emergence of heat-consumption of a heat carrier's usage in the systems corresponding to their thermal needs. However, due to a low hydraulic stability of the heating networks under various disturbances in them, misalignment occurs – the more, the lower their hydraulic stability.

The heating networks' regulation is reduced to a functioning regulation of separate systems of heat-consumption by changing, if necessary, hydraulic resistance and installed throttling devices. The criteria for a correct regulation of the heating networks are the following:

- establishment of the heat carrier's estimated consumption in a heating network and in each system of the heat-consumption;
- compliance with the required temperature difference in each system of the heat-consumption;
- calculated temperature maintenance in heated buildings.

In addition, it is necessary to remember that a detailed examination of the heating supply system and development of optimal operating regimes for a certain heating network should necessarily take precedence of the heating networks' regulation. On the basis of it, the adjustment (optimization) measures must be worked out and implemented to the fullest extent possible. It's impossible to achieve positive results without the development of an optimal hydraulic regime, measures, and their implementation in full for the heating networks.

The most effective solution of the above stated problems is the widespread adoption into practice of the heating networks' construction of pipelines with polyurethane foam insulation such as "pipe in pipe" (Figure 5.1 and 5.2).

Heat losses in the pipes of a new design are minimal, and the design itself can completely eliminate the pipeline's external corrosion. At the same time the pipelines' performance shows a high reliability and durability of a heating system, as well as a significant reduction in operating costs after the heating system's launch in action. New designs have another important advantage – the system of an operational remote control over moisture insulation, timely responses to a violation of the integrity of a steel pipe or polyethylene waterproofing covering and prevents from leaks and accidents in advance.

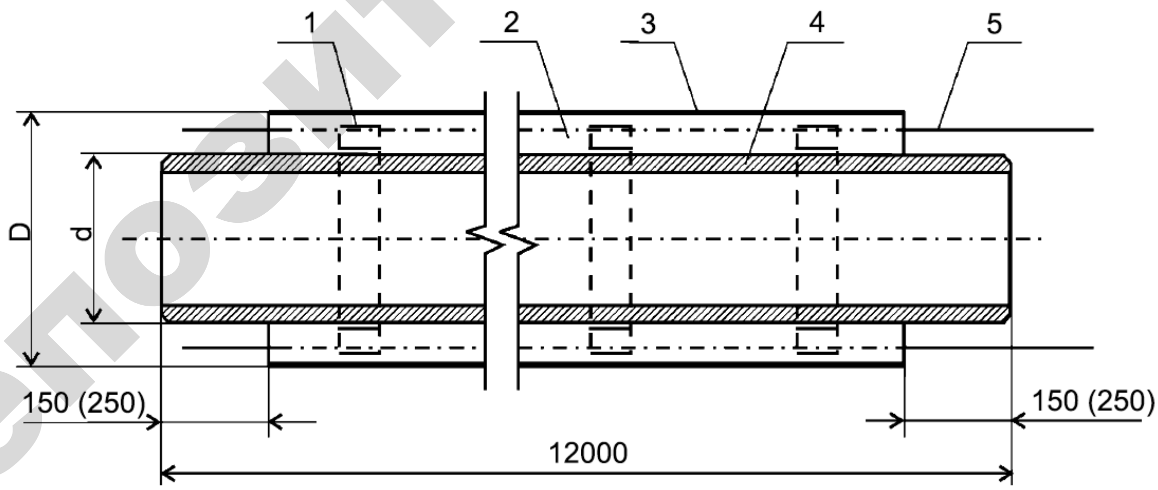


Figure 5.1. Design of a heat-insulated pipe:
1 – centering support; 2 – polyurethane foam insulation; 3 – mantle pipe of polyurethane; 4 – steel pipe; 5 – conductors-indicators of the operational remote control over moisture insulation

One of the energy-saving solutions of the heating networks is the use of flexible polymeric heat-insulated pipelines with heat insulation from semi-rigid polyurethane foam and a hydroprotective covering (Figure 5.3).

A delivery pipe is made of cross-linked polyethylene, which allows transporting a heat carrier with an operating temperature up to 95 °C.

The advantages of polymer heat-insulated pipelines can be illustrated by comparing them with metal counterparts:

First. Flexible pipes are delivered to a construction site in long segments up to 200 m in the bay or on a special drum. Metal pipes – by pieces of 8–12 m. Thus, an object of one kilometer in length accounts for 5–10 jump joints when laying the heating duct with flexible polymer pipes and about 100 joints using metal pipes.

Figure 5.2. Placement of PI-pipes in the channel (without pipe-couplings)

Second. When installing polymer pipelines there is no need for welding, pipe connection is made using special fittings. The one fitting's installation takes about 10–15 minutes and does not require highly qualified welders.

Third. The polymer pipeline's lifetime is at least 50 years, while a metal pipe (depending on the transported water quality through it) on average is only 10–20 years. The use of flexible polymer pipelines significantly reduces the time spent on erecting works, which leads to a cheapening of the heating networks' laying. In addition, a significant economic effect is achieved at the expense of costs' reduction of the related materials, required for the jump joints' insulation.

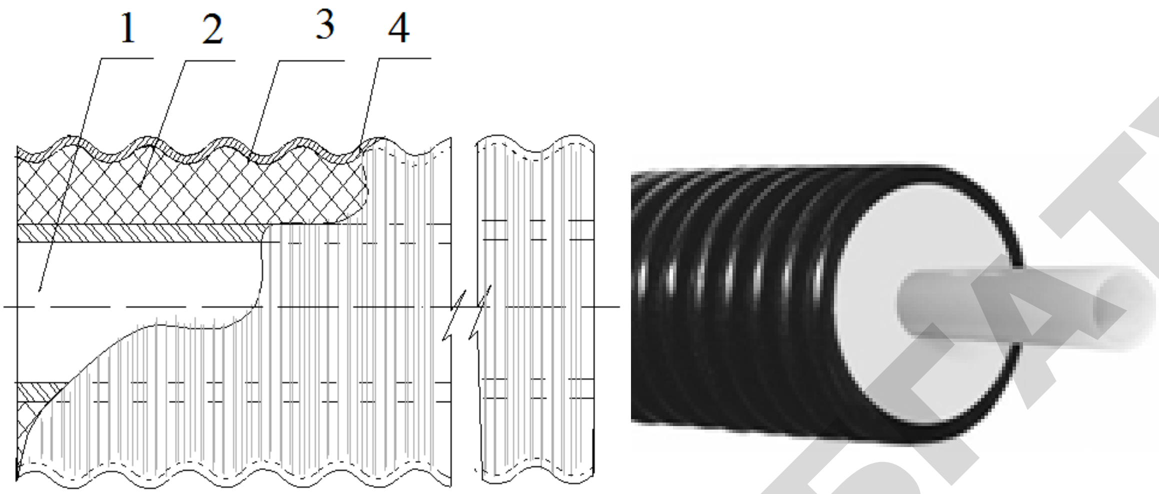


Figure 5.3. Flexible PI-pipe IZOPEKS:
1 – PEKS pipe; 2 – polyurethane insulation; 3 – polyethlene film;
4 – corrugated hydroprotective cover

However, there appear a number of serious difficulties while using them. The commonly used on the west flexible heat-insulated pipes, offered by the companies Brugg Rohrsysteme, Rehau, Uponor, Logstor, Isoplus and others, have limited diameters (typically till 110 mm) and were designed for small district heating networks, with moderate thermal loads. Therefore, their distribution in the market of Belarus is limited with the heat supplying organizations of small towns and not large-scale enterprises of the processing area of the agroindustrial complex, as well as villa constructions and agricultural towns.

As stated in the guidelines [27], during an operational period the water heating networks of the PI flexible pipes shouldn't be the subject to annual hydraulic tests, as well as tests on calculated temperature and heat losses, examinations on the existence of the stray currents' potential. This also results in economizing on means and working time. The key indicators of the PI flexible pipes are presented in Table 5.1.

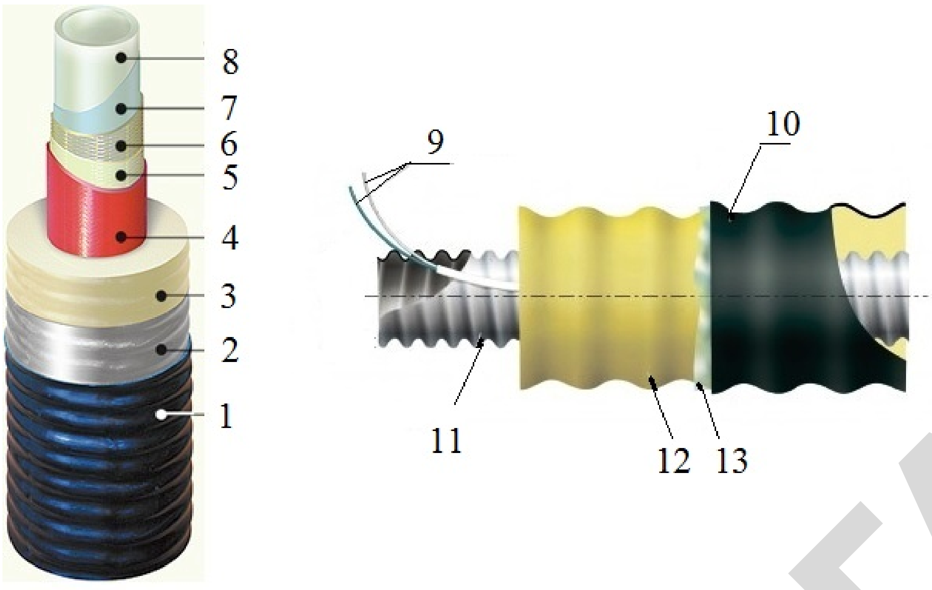
Table 5.1. Characteristics of a polyethylene pipe

Characteristics	Value
The average coefficient of a linear thermal expansion of polyethylene K^{-1} at temperatures from 0 °C to 70 °C	$1{,}5 \cdot 10^{-4}$
Thermal conductivity of a polyethylene pipe, W/(m·K)	0,38
Thermal conductivity of a polyethylene covering, W/(m·K)	0,43
Thermal conductivity of thermal insulation of polyurethane foam, with an average temperature of 50 °C, W/(m·K)	No more than 0,033

In addition to the PI-pipes similar types of flexible pipes “Izoproflex” and “Kasaflekx” are widely used (Figure 5.4 and 5.5), they have been developed and manufactured in the CIS countries (including the Republic of Belarus).

Figure 5.4. Flexible pipes laying “Kasaflekx”

For the first time while creating a pipe a reinforcing layer (kevlar) is applied, it allows using a pipe at a much higher pressure without increasing a wall’s thickness of a delivery pipe. None of the leading specialized companies in the world possesses such a technology as a reinforcing layer’s application. A new technology is called “Izoproflex”. The operational characteristics of pipes “Izoproflex” give the possibility to use them in the heating networks with a heat carrier’s temperature up to 95 °C and pressure up to 10 bars. Pipes “Kasaflekx” are intended for the networks with higher performance characteristics. A delivery pipe in them is corrugate; due to it the construction remains flexible and is made of chrome-nickel stainless steel, resistant to chlorinated water of the heating networks. Due to the operational characteristics of pipes “Kasaflekx” it’s possible to use a heat carrier with the temperature up to 130 °C (temporarily up to 150 °C) at a pressure up to 16 bars.



а) б)

Figure 5.5. The PI flexible-pipes Izoproflex (a) and Kasaflekx (b):
1 – containment from the high-pressure polyethylene; 2 – technological koronirovannaya film; 3 – semi-rigid polyurethane foam; 4 – composition based on copolymer ethylene; 5 – adhesive (oxygen-shielding layer); 6 – reinforcing layer (kevlar); 7 – adhesive; 8 – pipe PEX-a; 9 – signal cable; 10 – containment from polyethylene; 11 – delivery corrugated pipe; 12 – heat-insulation from polyurethane foam; 13 – barrier layer

In some heat points of the buildings' heating systems the pump mixing units and heat distribution stations are still being used. Since heat distribution stations practically do not give a chance of energy-efficient modernization of the heating systems and are incompatible with thermostatic valves, they must be replaced with the pump mixer circuits and independent systems with a heat exchanger. A setting of balancing valves will optimize the heat points' work, providing a project's costs at all loads, and therefore receive their design heat loss, as well as a correct temperature of the return water. Thus a significant energy saving is achieved and lifetime of equipment is increased.

The energy efficiency improvement of the heating networks consists in the following:

– optimization of the pipelines' section while relaying;
– pipelines' laying "pipe in pipe" with polyurethane foam insulation;
– replacement of mineral wool insulation for polyurethane foam with metal reflectors;
– electrochemical protection of metal pipes;

– application of the systems of a remote diagnostics of pipelines' conditions;

– use of justified regimes to reduce a heat carrier's temperature;

– exclusion of soil and sewage water suction into the underground heat transport systems;

– installation of heat meters in the central heat supply stations (CHSS) ;

– replacement of inefficient shell and tube heat exchangers in the central heat supply stations for plastic with the leaks' elimination;

– installation of adjustable speed drives to maintain optimal pressure in the networks (energy saving is 20–25 % and a reduction of accidents);

– closure of inefficient and unloaded boilers;

– conduction of measures to optimize the thermal conditions of the CHSS building and reuse of return water and ventilation heat;

– use of block heating points while upgrading their subscriber's inputs;

– adjustable valves' setting on heat supply into the loaded sections of the heating mains;

– use of mobile measuring systems to diagnose the heat's condition and supply, as well as to regulate heat supply;

– heat meters' installation at the entrances of the buildings' heat supply;

– introduction of the automated dispatching systems of the CHSS ;

– an integrated hydraulic balancing of the heating networks;

– employees' bonus payment implementing the networks' exploitation and the CHSS taking into account the energy efficiency indicators.

In general, the block heating point should comprise a combination of the following components:

– a metering and regulating heat energy unit to account for the actual heat carrier's consumption and heat, as well as adjustment (reduction) of a heat carrier's consumption in accordance with a predetermined temperature schedule;

– a heating unit to provide the required heat consumption depending on weather conditions, day time, days of the week, etc.;

– a hot water supply unit to maintain a normative water temperature (55–60 °C) in the hot water supply system;

– a ventilation unit to regulate the consumption of heat energy in accordance with the weather conditions and daytime.

The block heating points' application compared to a traditional house connection makes possible:

– to reduce costs of the heating point's creation;
– to save heat energy and funds;
– to improve the reliability of the building's heat supply;
– to simplify further modernization (automation) of the buildings' engineering systems.

6. Use of cogeneration plants

Traditional methods to generate heat and electric power are connected with a use of special equipment, which includes:

– thermal power plants (TPP) operating on fossil fuel with the use of water steam in turbines (steam-turbine plants – STP), combustion products (gas-turbine plants – GTP), and their combinations (steam and gas plants – SGP);
– hydraulic power plants (HPP) using the energy of a falling water stream, current, flood;
– nuclear power plants (NPP) using the energy of nuclear decay.

Thermal power plants can be divided into:

– condensation power plants (CPP), producing only electricity (they are also called SDPP – state district power plants);
– combined heat and power plants (CHP) – power plants with a combined production of electric and thermal energy;
– mini-CHP (a small combined heat and power plant) – thermal power plants serving for cogeneration in aggregates with unit capacity of 25 MW;cogeneration plants [4] (they assume a co-production of various products such as electric and ther-

[4] *A term cogeneration plants (co — joint, generation — production) is used as a synonym of terms mini-CHP and CHP.*

mal energy, as well as other products, such as thermal energy and carbon dioxide, electric, thermal energy and cold, etc.).

Energy conversion technology at TPP (CPP) can be represented as a chain of the following transformations:
internal chemical energy of fuel → heat energy of water (steam) → mechanical energy of rotation → electric energy.

The main energy efficiency indicator of a power plant is the efficiency coefficient (EC) of the electric power supply, called the electric efficiency coefficient of a power plant (ECP). It is determined by a ratio of released (generated) electric energy to consumed energy (heat of the burnt fuel) and it is 33–40 %.

Combined heat and power plants as well as the CPP give electricity to consumers, and besides thermal energy in the form of steam and hot water for technological needs of production and hot water for public utility consumption (heating, hot water supply). In case of cogeneration the heat of the spent steam in turbine (or gas) is given to the heat network, which leads to reduction in fuel consumption.

The diagram of the CHP with turbines of a poor vacuum is shown in Figure 6.1a. Pressure in the condenser of such a turbine is maintained in a way that saturation steam temperature should be high enough for the desired heating of the cooling water in the condenser. The diagram of the CHP (in Figure 6.1b) is the CHP in which the so-called backpressure turbines are applied. There is no condenser in these plants, and the exhaust steam from the turbine is directed through a streamline for production, where it gives the heat and condenses; the condensed steam returns from production to power boilers. The steam pressure at the outlet from the turbine is determined by production needs. The diagram of the combined heat and power plant with turbines of the spent steam is shown in Figure 6.1c. In this diagram part of the steam with sufficiently high parameters is taken from the turbine's intermediate stages. The exhaust steam is sent either for production or to special heaters-heat exchangers, in which this steam heats the water used for heating purposes.

The efficiency coefficient of the modern CHP is up to 90–92 %, but operating between two regimes depending on the heat consumption concerning electricity generation, the efficiency coefficient of CHP is typically 70–75 % and “the energy efficiency coefficient” of the achieved heat production is usually 200 % (comparing with the CPP, CHP approximately doubles the use of energy contained in fuel).

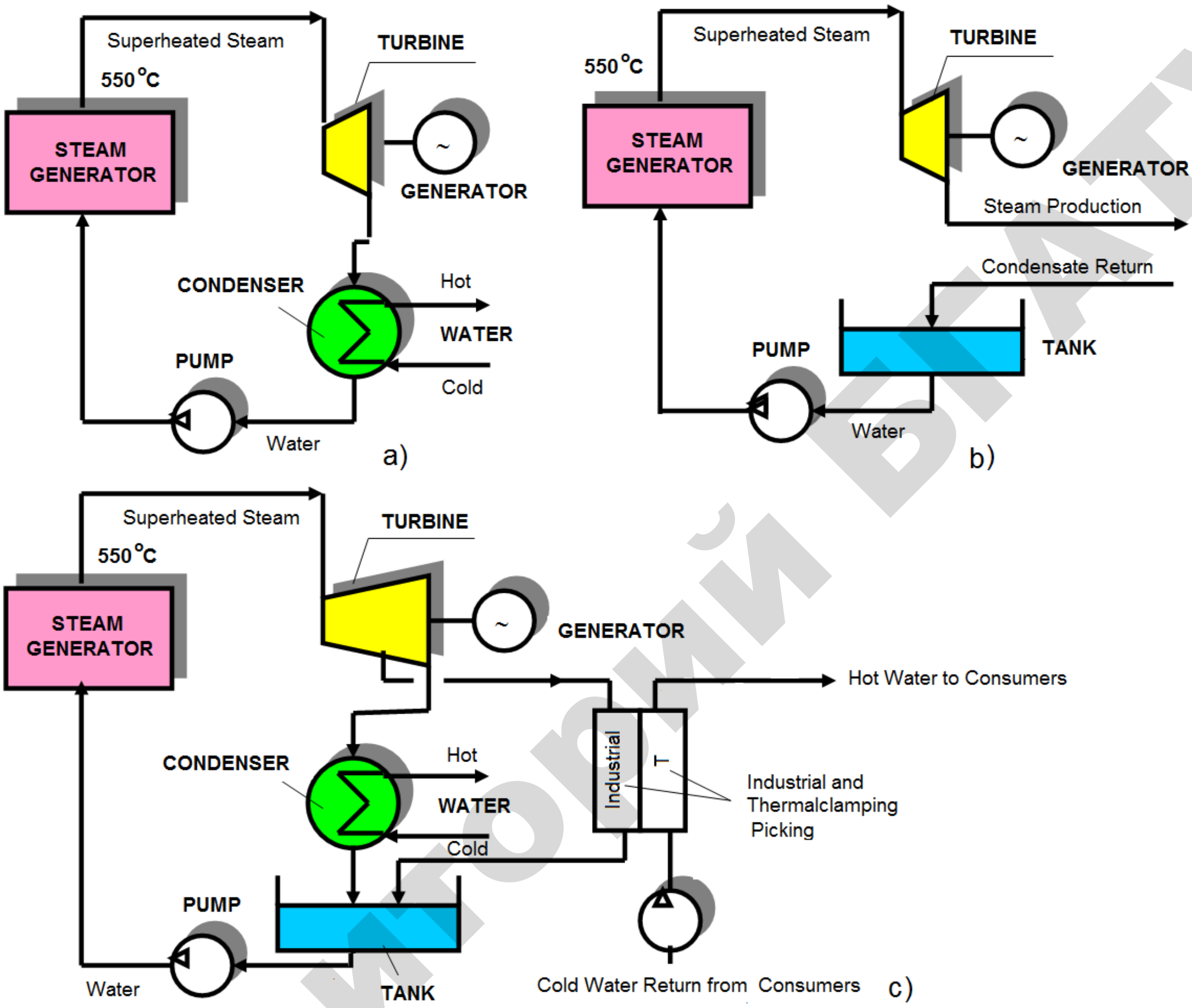


Figure 6.1. Principal diagrams of modern combined heat and power plants

Besides, generally, the combined generation of heat and electricity saves about 30 % of fuel compared to a separate production of electricity and heat [32].

The mini-CHP is a compact power plant on the basis of a piston engine of internal combustion, operating on natural gas and generating simultaneously heat and electric energy. The mini-CHP is designed to produce combined electric energy of alternating current and thermal energy in the form of hot water or steam. The application of this equipment allows any user to become independent from the power outages or its shortages simultaneously obtaining the autonomous heat supply.

The mini-CHP may be located outside or inside of a building and has several performance variants: basic, open (without a noise muffler) in a container. The mini-CHP may be installed on any new projects under construction: industrial plants, shopping malls, office centers, residential neighborhoods, and cottage settlements.

The advantages of the mini-CHP are:

– combination of a production process of electricity and heat;
– low unit cost of heat and electric power;
– quality and continuity of power supply;
– conformity to the European environmental standards;
– a low payback period and a long life of electrical power unit and equipment;
– a close proximity to the end consumer and no costs of communications' construction and unavoidable losses of energy transmission through the networks;
– allows avoiding costs of expensive high voltage electricity transmission lines;
– the CHP are compact;
– the mini-CHP efficiency commissioning;
– optimal conformability to the regime of a multiple start and stop;
– low costs of the mini-CHP energy production;
– simplicity and operational convenience – the entire process of the plant's operation control is fully automated;
– high reliability of the main components and aggregates.

Environmental safety is another advantage of the autonomous CHP. These plants have a low level of hazardous emissions (CO and NO_x) into the air and they conform to the emission standards. If necessary, the level of NO_x emissions can be reduced doubly with the help of the engine adjustment (due to a slight decline of the efficiency coefficient, approximately by 1–2 %); the level of CO emissions can be reduced by setting additional oxidation catalysts into the exhaust system.

The fuel material of the mini-CHP is the following:

– *gaseous fuel*: main natural gas, liquefied natural gas and other combustible gases;

– *liquid fuels*: oil, fuel oil, diesel fuel, biodiesel, and other flammable liquids;
– *solid fuels*: coal, wood, peat and other biofuels.

The most efficient fuel is the main natural gas and also associated gas.

Since the plant's operation is fully automated, the operator's permanent presence at the workplace is not required. If necessary, monitoring of the mini-CHP functioning can be remote via the Internet. A piston engine **(**of internal combustion), gas turbine, steam turbine, and their combinations can be used as the mini-CHP motor.

Engines of internal combustion (EIC) are used for the autonomous plants' drive, which are often used as backup power sources, or in areas where there is no centralized power supply. When equipped with the heat exchange equipment or a waste-heat boiler, they are converted to the mini-CHP, whereas the heat of exhaust gases is used for heating and hot water supply, and in models with deep utilization the heat of cooling systems and lubrication are also used. About a third of the fuel energy is converted into mechanical work. The rest of it is converted into thermal.

In addition to diesel EIC, gas and gas-diesel engines are used. The first can be equipped with several carburetors, and it gives the possibility to run on different kinds of gas.

The gas turbine engines are widely used in energetics, although they are inferior to piston engines in size of the relative capital investments into electric and heat energy production (about 20 %). The main components of a gas-turbine engine are a gas-generator and a power turbine; they are located in the same housing. The gas-generator includes a turbo-compressor and a combustion chamber, where a high temperature flow of gases is created, which affects the power turbine's blades. The thermal performance is provided at the expense of heat utilization of exhaust gases with a heat exchanger, water-heating or a steam heat-recovery boiler.

Cogeneration is a modern, highly efficient and at the same time ecological method to generate electricity. The resulting heat in a cogeneration process is not released into the atmosphere, but is used for heating or for industrial purposes. Thanks to the use of this heat in the premises' heating system or water heating, there is no need to purchase additional heat from other sources, which saves financial resources considerably. In addition, thanks to the combined energy generation technology, the fuel use efficiency is significantly reflected in the environmental specifications on the number of CO_2 emissions. Cogeneration distinguishes itself by a very high measure of the useful energy usage, contained in fuel, which could be about 95 %.

Cogeneration of plants is complex technological equipment designed for co-production of heat and electric energy (Figure 6.2). A cogeneration plant comprises the following main assemblies and components: an engine of internal combustion, a generator, a system of heat exchangers and a control system that allows managing the plant both on-site, and from a remote location via a computer or a cell phone.

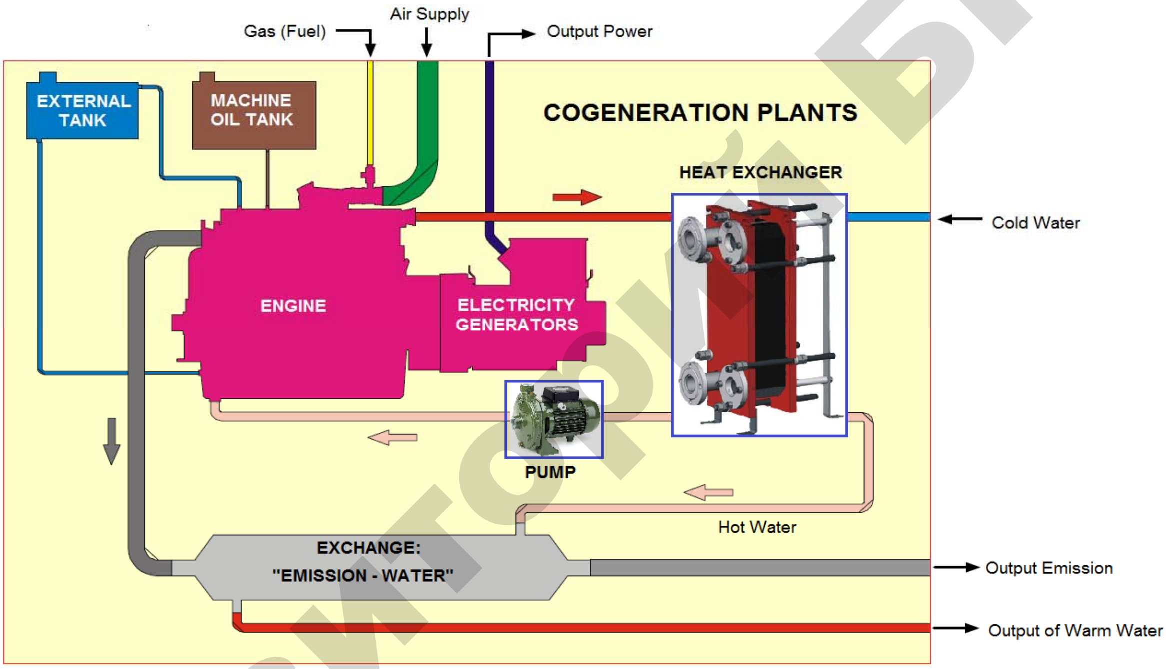


Figure 6.2. Principal diagram of a cogeneration plant (the mini-CHP)

The main fuel for combustion in cogeneration plants is natural gas. However, in recent years the amount of equipment operating on biogas, landfill gas, sewage gas or the combustion of alternative fuels, such as coal mine gas, associated gas, and others has dramatically increased.

Nowadays such companies as ELTECO, FITER, GE Jenbacher, TEDOM and others have become the leaders to produce cogeneration plants.

A standard production of cogeneration plants:

– without a protective housing element from noise (one of the variants of this production is the separation of the thermal module from the engine-generator module; this technical solution is available for high-power cogeneration plants);

– a compact block production in a protective housing element from noise (the advantage of this option is a short installation period and a low noise level, plants of this production are in great demand);

– in a container (designed to be placed in the open space outside of the residential or industrial facilities; the advantage of this production is a fast installation and resistance to climatic influences);

– production of Basic type (in a closed special building).

An obvious advantage of cogeneration is the ability to supply electricity in a precisely defined volume in comparison with an alternative way of electricity generation using renewable energy sources such as the sun or wind. Thus, cogeneration can be referred to regulated energy sources. With the help of a centralized management system of several co-generation plants it's possible to create the so-called distributed power plants (sometimes called as virtual power plants); the systems consisting of a large number of small power sources located in different regions, which work as one source of high capacity. These power plants are able to provide some system services, align the fluctuations in the electricity supply from solar and wind energy. The energy-saving principle of cogeneration is visually illustrated in the diagram below (Figure 6.3).

The usage of cogeneration technology increases the power plant's efficiency by 30–40 % and reaches the calculated total efficiency coefficient in the amount of 95 %, and the cost of the generated electricity is much cheaper than the tariffs of the central power line (central heating and power plants). The use of cogeneration plants (the mini-CHP) is advantageous due to the absence of electricity and heat losses, as well as a need for a constant renovation of the old heat transport systems.

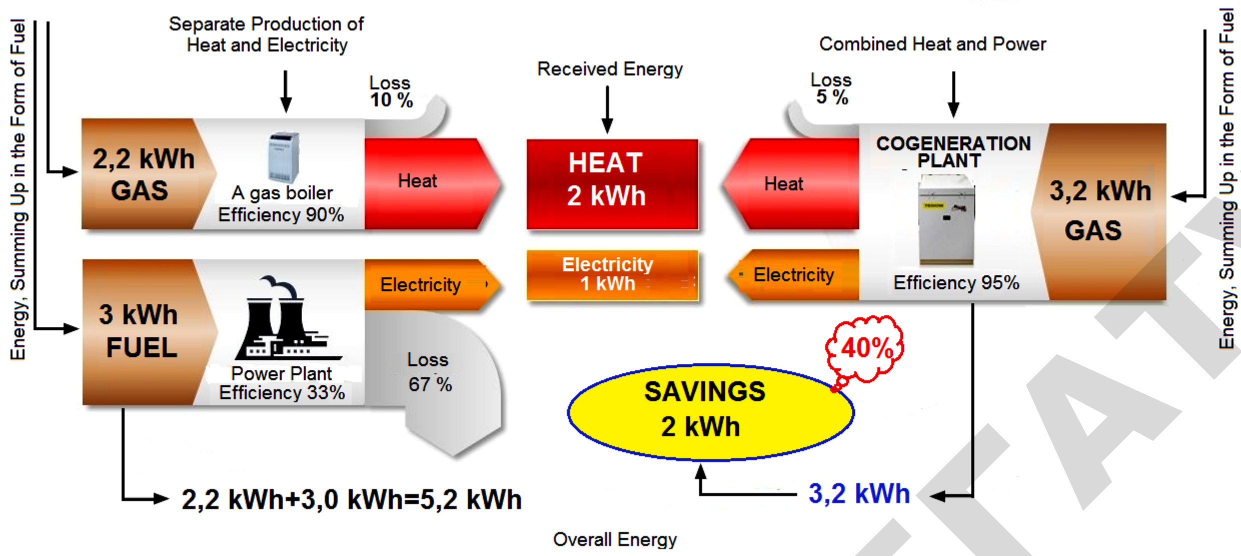


Figure 6.3. The advantage of a combined generation method of thermal and electric energy

Trigeneration is a combined generation of electric, thermal and cold energy. Cold is produced with an absorption refrigeration machine consuming not electric but thermal energy. Trigeneration is advantageous because it gives the opportunity to use heat recovery efficiently not only for heating in winter, but also in summer for air conditioning of premises or technological needs. This approach allows using a cogeneration plant throughout the year with high efficiency.

Water cooling in a trigeneration plant (Figure 6.4) happens due to an absorption process of hot water. Moreover, when connecting compressor refrigeration plants to a trigeneration plant it's possible to obtain not only chilled water but also the temperature below 0 °C. The benefit of a trigeneration plant's usage compared to a cogeneration plant is obvious because thanks to its use it's feasible to efficiently distribute heat excesses produced with a gas piston plant.

It's the question of heat recovery in summer that often leads to a load drop of cogeneration plants, or to the cogeneration plants' exploitation of less capacity than it's actually required. When using heat to produce cold a cogeneration plant can work at full capacity even in summer, and the resulting heat will be used for its intended purpose, where it is required to air-condition the indoor premises – in banks, hotels, in shopping malls, administrative centers, hospitals, sports complexes, etc.

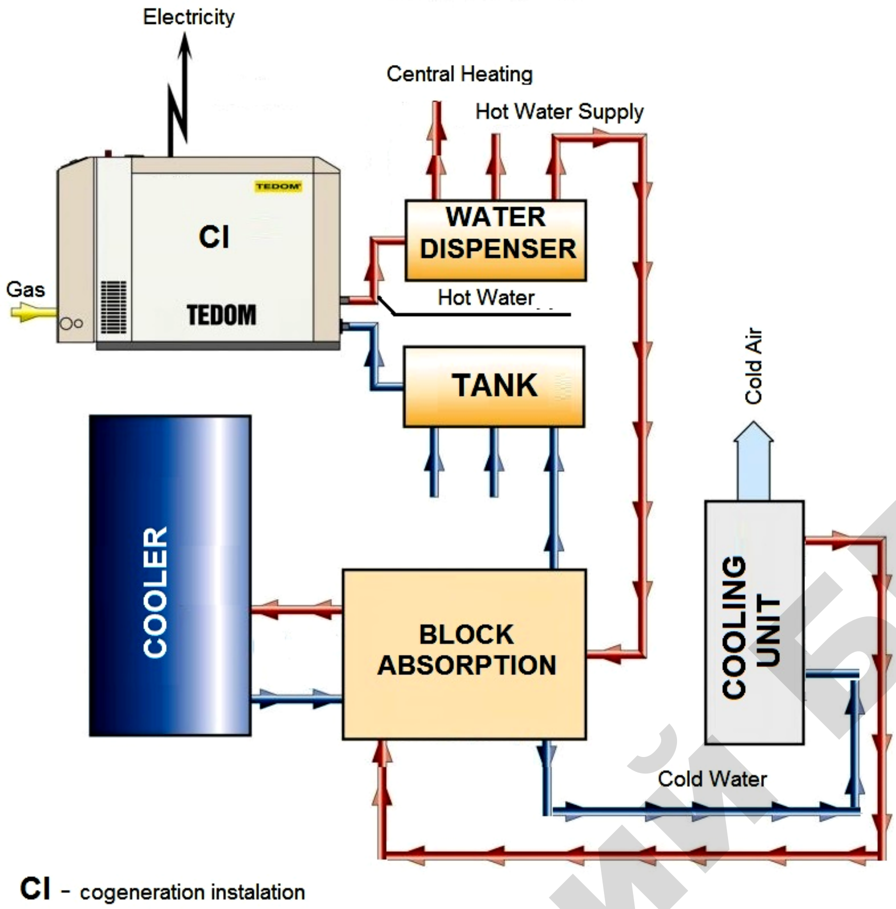


Figure 6.4. Typical diagram of a trigeneration plant for water cooling

The advantages of trigeneration include: cost effectiveness (heat excesses are used to generate cold); minimal wear (a simple chiller's design – of a cooling water installation); low noise (an absorption installation runs silently); environmental (water is used as the refrigerant); high efficiency (the efficiency coefficient reaches up to 92–95 %).

A key point in trigeneration designs is an absorption refrigerating machine (ARM). The absorption refrigerating machines is a separate class of devices, which is used to generate cold for air conditioning and other cooling processes. The absorption refrigerating machines are environmentally friendly, running on natural refrigerants, oil, gas and their derivatives, biofuel, steam, hot water, solar energy or energy heat excess of gas turbines of piston power plants are used as fuel. The ARM is produced by such famous companies as: Carrier, Trane, York, Century, Broad.

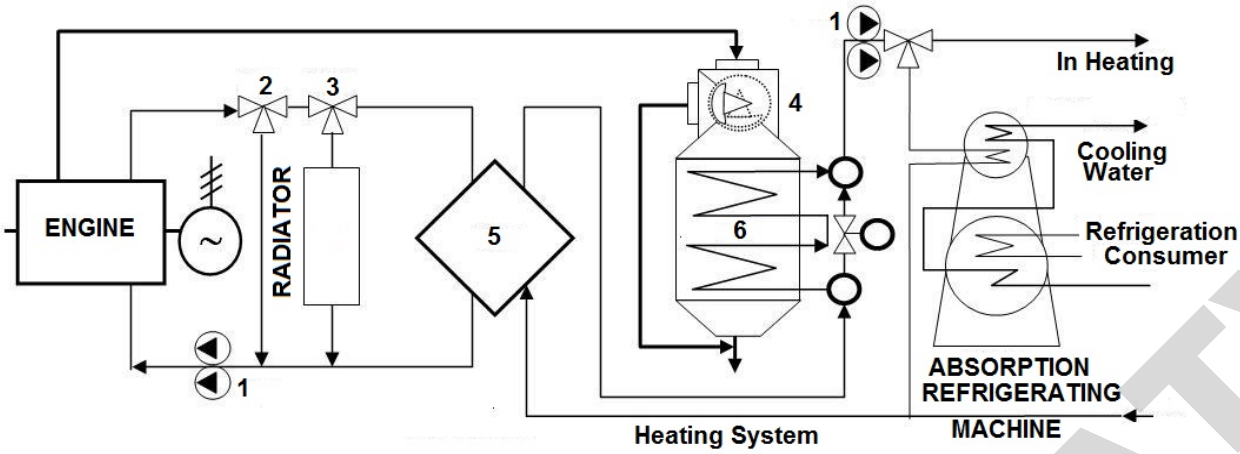


Figure 6.5. The simplified principal diagram of trigeneration:
1 – circulating pumps; 2 – thermostat; 3 – three-way valve;
4 – control damper valve: 5 – intermediate heat exchanger;
6 – waste-heat boiler

An example of a trigeneration plant, combining a cogeneration plant with the ARM, which allows using heat excess of hot water for cooling, is presented in Figure 6.5. The trigeneration diagram with the use of two cogeneration modules and the ARM is presented in Figure 6.6.

An operating principle of the absorption refrigerating machines is based on the fact that water is evaporated in a vacuum environment at low temperatures, and during evaporation it takes heat from the air of conditioning system. In the ARM the solution of lithium bromide (LiBr) is a very strong water absorbent that absorbs steam (carrying the heat of cooling water), turning into a dilute solution, which is pumped into a generator, where it's evaporated, heated from hot steam, water, exhaust gases, etc. The concentrated LiBr solution returns to the absorber, and moisture steam is directed to the condenser, in order to the repeat the process. The efficiency coefficient of the absorption refrigerating machines equals to 0,64–0,66.
The ARM produce chilled water using two substances (for example, water and lithium bromide salt) that are in thermal equilibrium, which are separated by heating, and then recombined by the heat removal. The targeted supply and removal of heat in a vacuum environment under alternating pressure (approximately 8 mbar and 70 mbar) create an imbalance of substances thus exposing them to desorption or ab-

sorption. To produce chilled water at temperatures' range from 6 to 12 °C water (refrigerant) and lithium bromide (absorbent) are usually used. To produce a low-temperature cool up to –60 °C ammonia (coolant) and water (absorbent) are used. The ARM special feature is the use of not a mechanical refrigerant but a thermo-chemical compressor for vapor compression.

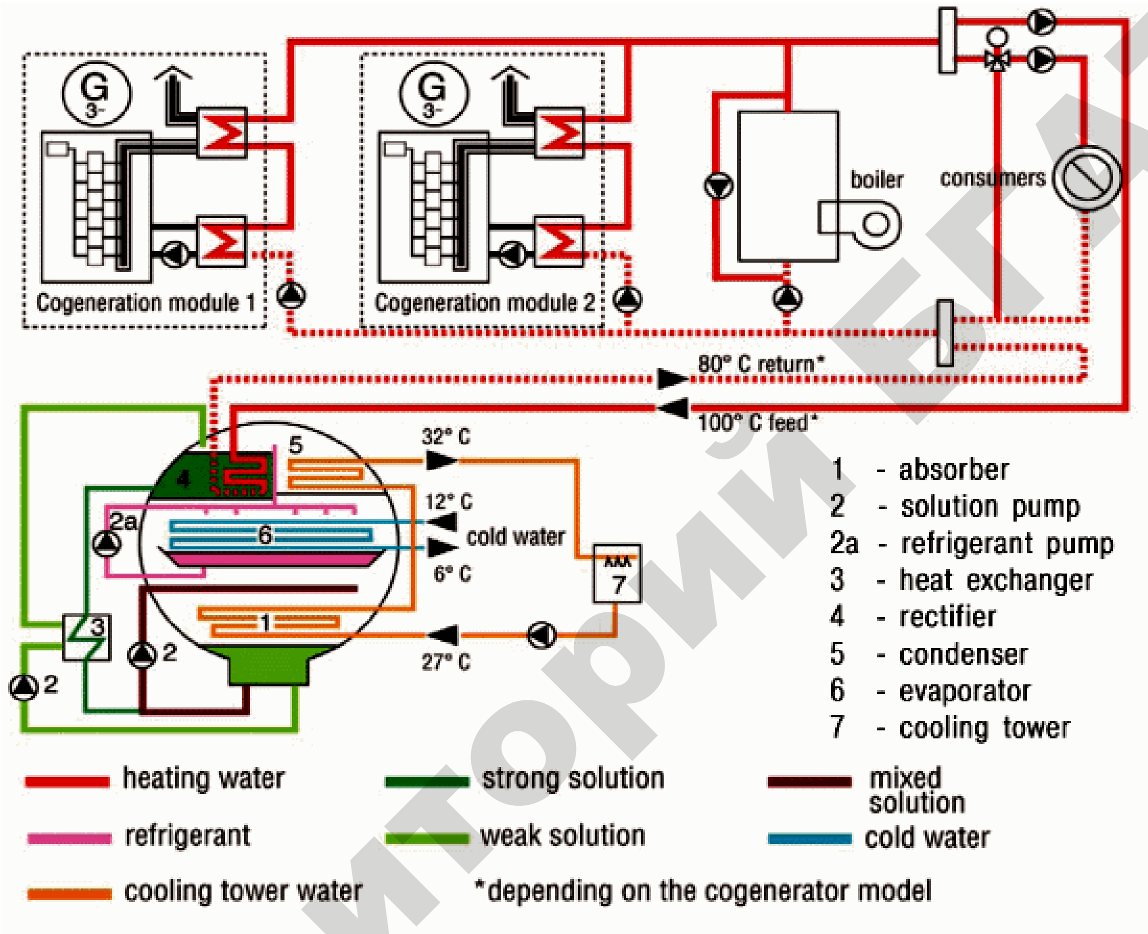


Figure 6.6. Trigeneration diagram with the use of two cogeneration modules and the ARM

Connection of cogeneration and absorption plants is possible according to the two circuits (Figure 6.7): type A or type B.

Type A suggests the existence of its own heat exchanger of combustion products in a cogeneration plant. The heat energy of the cogeneration plant is used to heat water of the heating system or to produce cold in the absorption plant. The advantage of this circuit is that a three-way valve enables a smooth regulation of the exiting heat intended for cooling or heating.

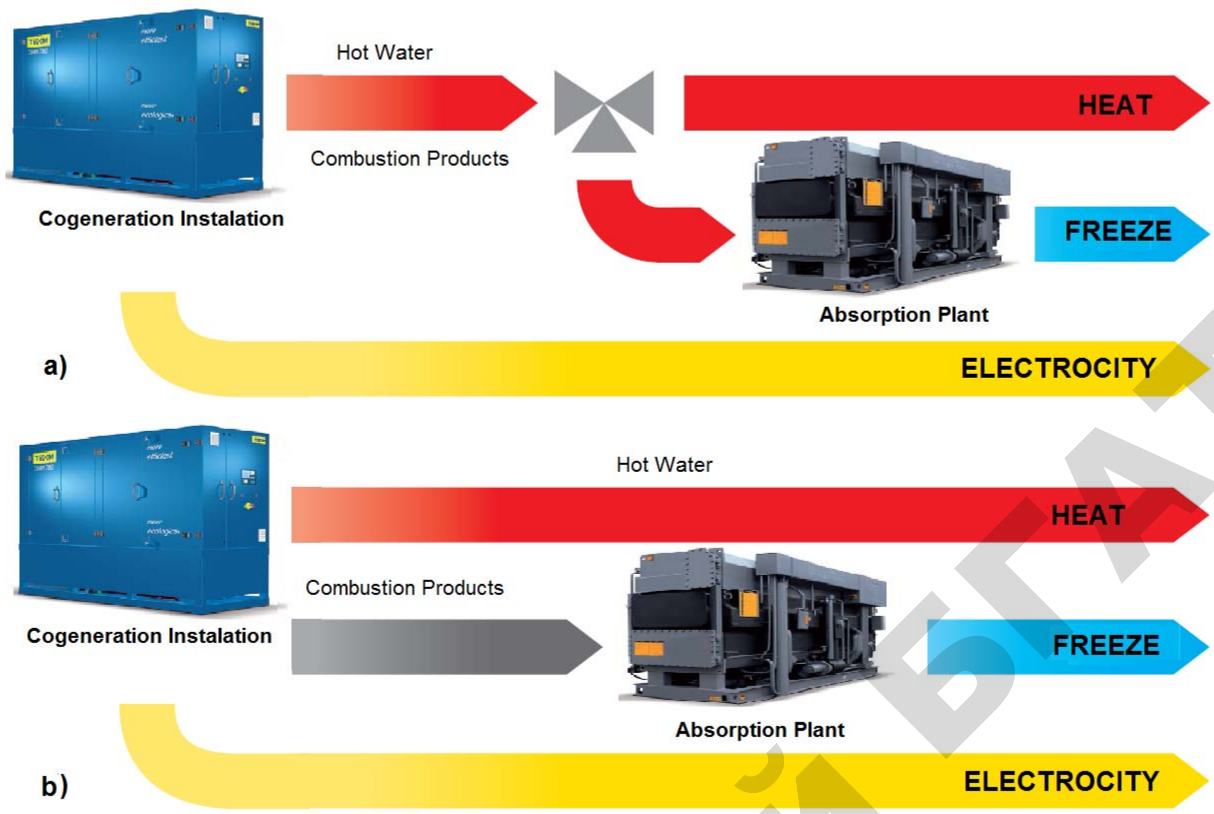


Figure 6.7. Connection possibilities of cogeneration and absorption plants in a trigeneration mode: a – type A; b – type B

Type B suggests that there is no its own heat exchanger of combustion products in a cogeneration plant, and flue gases are delivered directly into an absorption plant and there is a heat exchanger of combustion products. The advantage of this circuit is a sharp increase in absorption efficiency when using the combustion products' energy in comparison with the use of hot water energy.

The electric energy generation and management of cogeneration plants have their own peculiarities, which are mainly in the operational modes. The possible operational modes of cogeneration plants are shown in Figure 6.8 and 6.9.

In Figure 6.8 the varieties of the so-called "isolated operation" are presented:

– a basic mode (the operation of one or more cogeneration plants in an autonomous mode is possible without the presence of an external electric network);

– with the common exit's switching on (the operation of several cogeneration plants in an autonomous mode without the presence of an external electric network and the possibility of the circuit breaker's switching off (3) only after the launch of all cogeneration plants).

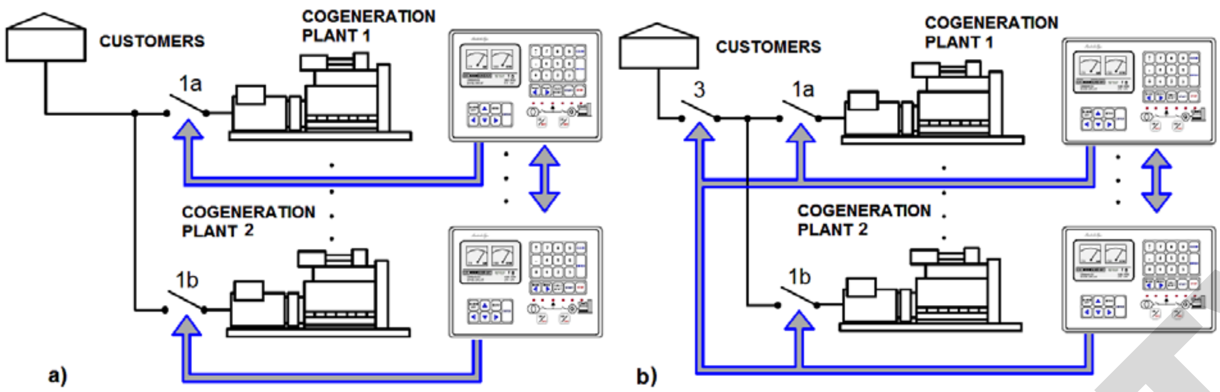


Figure 6.8. The basic operational mode of cogeneration plants:
a – basic; b – the common exit's switching on

In Figure 6.9 the varieties of a parallel mode of cogeneration plants' operation with an electrical network are presented:

– without the possibility of an isolated operation (operation of one or several cogeneration plants is possible only when there is an external electric network);

– with the possibility of an isolated operation without a reverse phasing, with the power outage of an electric network from the outside (operation of one or several cogeneration plants is possible only when there is an external electric network);

– with the possibility of an isolated operation without a reverse phasing, with the power outage of an electric network from the outside (losing an electric network after the circuit breaker's switching off (2) cogeneration plants are ready to work in an autonomous mode);

– with the possibility of an isolated operation without a reverse phasing (operation of several cogeneration plants: losing an electric network cogeneration plants disable the grid circuit breaker (2) and go on working in an autonomous mode, after the electric network's return cogeneration plants are stopped and the switch is switched on (2);

– with the possibility of an isolated operation with a reverse phasing (operation of one or several cogeneration plants: losing an electric network cogeneration plants disable the grid circuit breaker (2) and go on working in an autonomous mode, after the electric network's return cogeneration plants are synchronized to the electric network);

– with the common exit's switching on, with the possibility of an isolated operation without a reverse phasing (operation of several cogeneration plants);

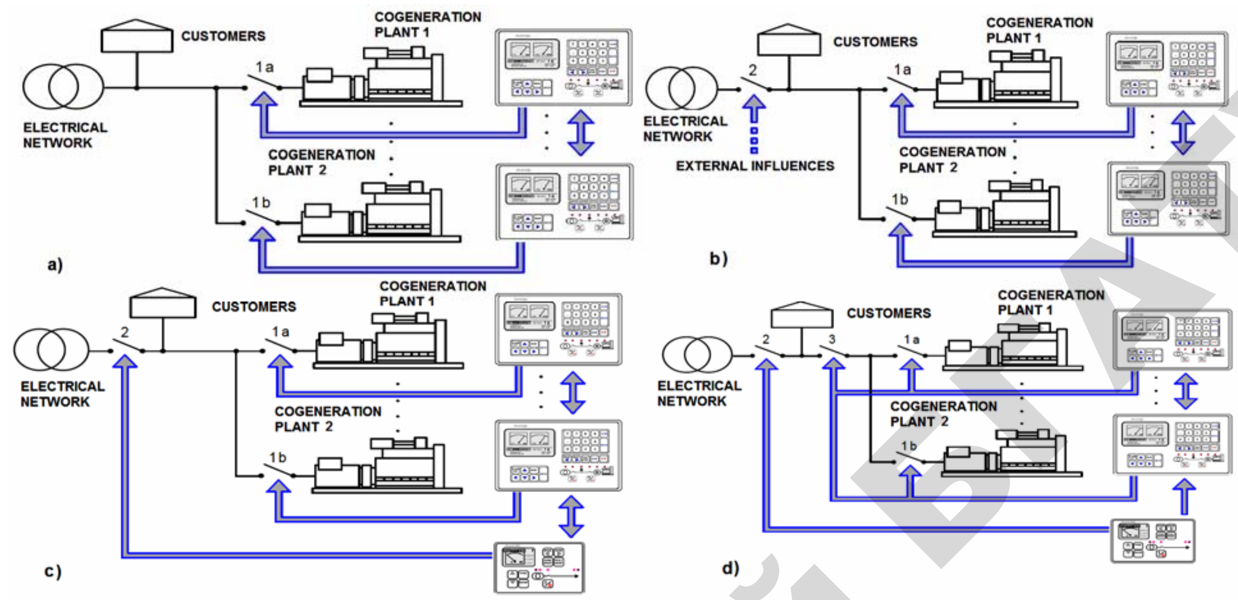


Figure 6.9. Parallel operation of cogeneration plants with the electric network: a – without the possibility of an isolated operation; b – with the possibility of an isolated operation without a reverse phasing, with the power outage of an electric network from the outside; c – with the possibility of an isolated operation without and with a reverse phasing; d – with the common exit's switching on, with the possibility of an isolated operation without and with a reverse phasing

– with the common exit's switching on, with the possibility of an isolated operation with a reverse phasing (operation of several cogeneration plants);

Some typical connection patterns of cogeneration plants are also proposed in appendix 4.

In Belarus, cogeneration plants are widely used in various spheres of the national economy and have a strong tendency to be developed (see Table 6.1–6.4).

Table 6.1. Disposal objects of solid municipal wastes, where it's technically and economically useful to introduce cogeneration plants

Location of disposal objects of solid municipal wastes	Project capacity, thous. m^3	Working lifespan, years	Capacity utilization of disposal, %	Electric capacity of the cogeneration plant, MW	Commissioning year
Novopolotsk	2 285	16	88	0,22	2015
Orsha	4 925	24	100	0,40	2015
Lida	3 600	27	79	0,30	2015
Soligorsk	2 427	37	100	0,20	2014
Bobruisk	4 660	26	60	1,00	2014

Table 6.2. Potential to construct power plants working on sewage wastes

Region	Sewage wastes, thous. m^3 in a year	Approximate yield of biogas, thous. m^3 in a year	Volume of replaced natural gas, thous. m^3 in a year	Capacity of a cogeneration plant, MW
Brest	60 469,90	6769,02	5 898,72	4
Vitebsk	40 056,30	4483,91	3 907,41	1,5
Gomel	52 502,00	5877,09	5 121,46	2,0
Minsk	42 412,30	4747,65	4 137,23	1,7

Table 6.3. Construction of biogas complexes in the agricultural sectorin 2012-2015 [36]

Region	Amount of objects, pieces	Total electric capacity, MW	Object replacement	Commissioning year
Brest	3	1,7	3951	2014
Vitebsk	1	0,3	697	2014
Gomel	3	3,0	6972	2014
Mogilev	1	1,2	2789	2015

Table 6.4. Potential output of the biogas plants' construction in the agricultural sector in terms of regional make-up

Region	Capacity of cogeneration plants, MW	Fuel replacement, thous. t	Farm and farm's status
Brest	11,7	26,2	Cattle farm (in operation)
Vitebsk	15,2	34,1	Cattle farm (in operation)
Gomel	7,3	16,4	Cattle farm (in operation)
Grodno	14,5	32,6	Cattle farm (in operation)
Minsk	12,1	27,2	Cattle farm (in operation
Mogilev	9,8	21,9	Cattle farm (in operation)
Total:	**70,7**	**158,3**	
Brest	11,7	26,2	Cattle farm (being designed)
Vitebsk	38,8	86,8	Cattle farm (being designed)
Gomel	11,1	24,9	Cattle farm (being designed)
Grodno	25,1	56,2	Cattle farm (being designed)
Minsk	6,6	14,7	Cattle farm (being designed)
Mogilev	0,8	1,7	Cattle farm (being designed)
Total:	**94,1**	**210,6**	
Brest	11,8	31,6	Pig complex (in operation)
Vitebsk	13,4	36,1	Pig complex (in operation)
Gomel	9,7	26,2	Pig complex (in operation)
Grodno	15,6	42,0	Pig complex (in operation)
Minsk	14,8	39,7	Pig complex (in operation)
Mogilev	7,5	20,2	Pig complex (in operation)
Total:	**72,8**	**195,8**	

Region	Capacity of cogeneration plants, MW	Fuel replace-ment, thous. t	Farm and farm's status
Brest	6,1	13,7	Pig complex (project)
Vitebsk	5,9	13,3	Pig complex (project
Gomel	1,5	3,3	Pig complex (project)
Grodno	2,4	5,3	Pig complex (project)
Minsk	11,9	26,7	Pig complex (project)
Mogilev	4,0	8,9	Pig complex (project)
Total:	**31,7**	**71,1**	

The company FILTER is the official distributor of GE Jenbacher in Belarus and since 2003 it has delivered gas reciprocating engines for cogeneration plants (unit capacity is from 0,3 to 4,0 MW) more than 150 MW of electric capacity (Figure 6.10).

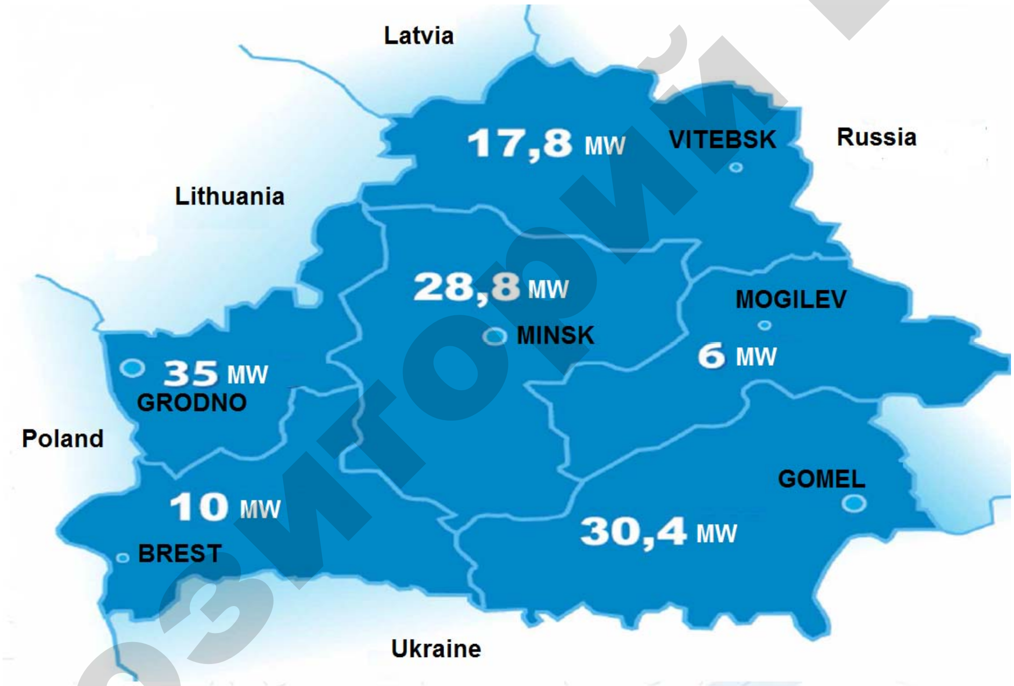


Figure 6.10. Installed capacities of cogeneration plants of the company FILTER (GE Jenbacher, Austria) in Belarus

The main technical and technological solutions presented by the company are the following:

– implemented projects of a standard cogeneration-based district heating;
– improvement of industrial consumers of steam;
– implementation of the special design solutions in the field of trigeneration;

– greenhouses’ energy supply;

– energy supply of drying systems and installations;

– projects with the application of biogas installations;

– the energy supply of industrial heating cycles of thermal oils;

– implemented projects in the field of technology of associated gases and fuel with a high proportion of H_2.

Micro-turbine installations are one of the plants’ varieties producing combined heat and electric energy. The company Calnetix Power Solutions started manufacturing micro-turbines in 1997. From 1997 to 2000, it produced 45 and 60 kW installations T45 and T60 type, and from 2000 to 2003 it produced installations TA80, 80 kW. From 2004 to the present moment, the company has been producing only 100 kW installations. These models:

– installation TA-100 RSNR for the combined generation of electric energy and heat (co-generator) with electric capacity of 100 and heat capacity is up to 200 kW;

– installation TA-100 R for the electric energy generation (power plant);

– installation TA-100 Offshore for electric energy generation to work on oil and gas-production platforms in the housing made of stainless steel;

– installation TA-100 SC (simple circle) without a recuperator for electric energy generation to work on associated gas.

Depending on the operational conditions the micro-turbine installations TA-100 and TA-RSNR 100 R are produced in two versions: for the indoor or outdoor exploitation in the premises. The installations for the outdoor exploitation can be manufactured in a version for the ambient air temperature: up to –30 °C and up to –40 °C.

A micro-turbine installation is a product of a full operational readiness. While designing its construction a block-modular principle was used, with the help of which, if it is necessary a separate unit can be replaced instead of a product. All the main and auxiliary systems and components are mounted on a single space frame. A protective housing with sound insulation is used to protect against external influences.

The installation comprises (Figure 6.11): a turbine generator; a combustion chamber; a recuperator; a heat insulation system with a heat recovery boiler; an oil system; a fuel system (with a gas-booster compressor); a power electronics module (rectifier transformers, inverters); a digital automatic control system FADEC of a turbine generator and power electronics with a control panel of the operator; an air cooling system of the under bonnet space and power electronics; an internal power supply system 24V.

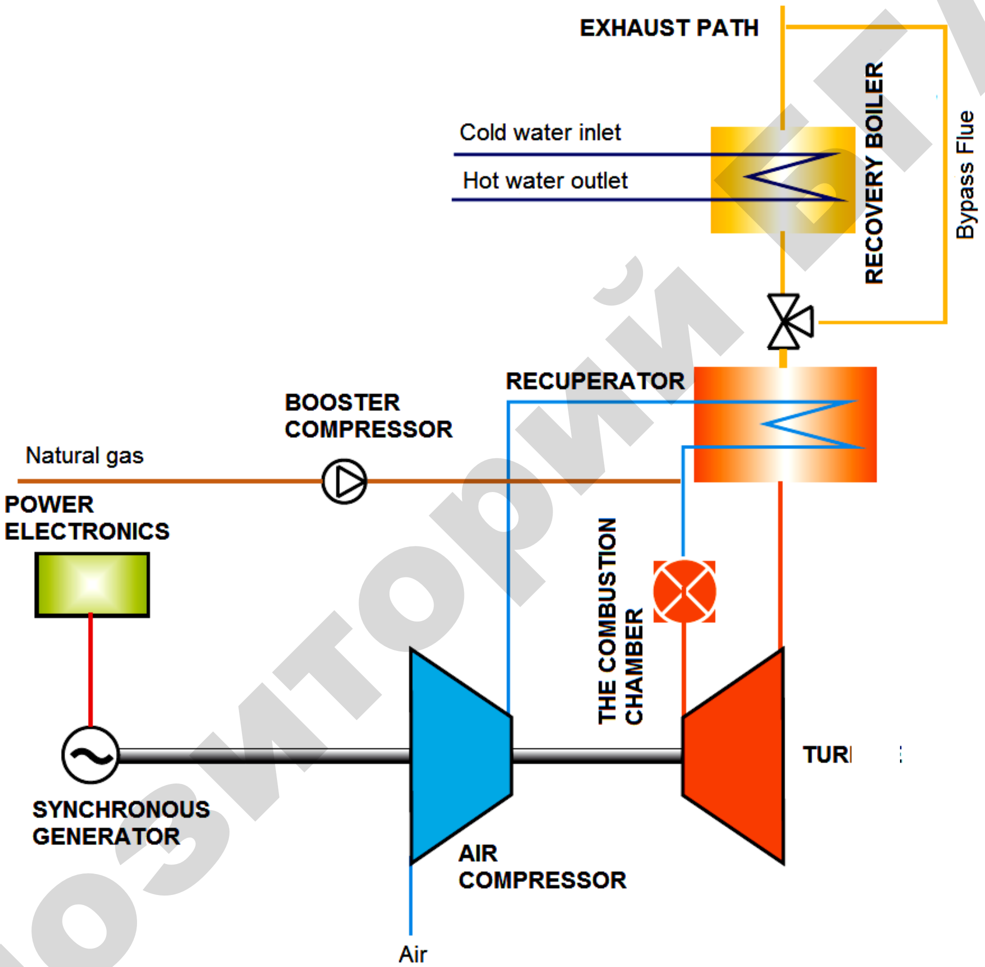


Figure 6.11. A functional design of a microturbine installation

The purified ambient air enters the air intake duct from which it moves to the exit of the turbines' compressor. In the compressor, the air is compressed and thereby is heated to the temperature of 250 °C. After that the heat exchanger (recuperator) is additionally heated up to the temperature of 500 °C; thanks to the usage of such a solution it's possible to improve the installation's electrical efficiency approximately in 2 times.

Further preceding a combustion chamber the heated compressed air mixes up with gaseous fuel of high pressure, from where a homogeneous gas-air mixture enters a combustion chamber for burning. An operational built-in booster compressor is used to increase pressure of natural gas. The air pre-mixing with gaseous fuel reduces the emission level of exhaust gases. Leaving the combustion chamber, exhaust gases heated up to the temperature of 926 °C enter a turbine’s wheel where expanding they perform work: rotating it, a compressor’s wheel and a high-speed synchronous generator arranged on the same shaft. After leaving the turbine’s wheel through the flue duct, the exhaust gases with the temperature up to 648 °C get into the recuperator,where they give up their heat to the compressed air after the compressor. The temperature of the exhaust gases after the recuperator reduces up to 310 °C. At the recuperator’s exit there is a bypass damper which directs the exhaust gases to a boiler-utilizer or through the bypass flue duct to the exhaust pipe. In the boiler-utilizer (in a gas and water heat exchanger) the exhaust gases give up their heat to the network water which is there heated up to the required temperature.

Depending on the manufacturers the rotor’s rotation frequency is 100,000 r/min. The rotor’s rotation frequency in TA-100 installations does not depend on load and automatically maintained at the level of 68000 r/min. As a result, it’s possible to assume the existed electrical load (up to 100 %) without any additional storage batteries for 0,3 s at once.

Technical characteristics of a micro turbine installation TA-100 RCHP (Figure 6.12) are presented in Table 6.5.

Table 6.5. The basic technical characteristics of the installation

Characteristics	Units of measure	Value
Electric capacity	kW	100
Heat capacity (max/HWS/heating)	kW	200/172/160
Electric efficiency coefficient	%	29
Maximum and total efficiency coefficient	%	no less than 87
Type of the electric generator	high-speed synchronous	
Noise level at a distance of 1 m	dB	75
Noise level at a distance of 10 m	dB	62
Temperature of the exhaust gases at the exit	°C	about 310

Figure 6.12. Block of microturbine installations at OJSC "Glubokoe dairy-canning factory", Vitebsk region

According to a practice of the microturbine installations' operation at the enterprises of the agroindustrial complex of the Republic of Belarus, these installations are not reliable. They were created in the United States to use them as a primary engine of an aircraft gas-turbine engine having a limited resource.

At the enterprises of the Republic of Belarus, where they were exploited, they went wrong almost anywhere. Today, at a "Glubokoe dairy-canning factory" the two installations out of five are in operation, but not at a full load (about 70 %).

Today it is possible to make a conclusion that they were adopted premature at the sites of the agroindustrial complex as combined installations producing heat and electric energy.

Along with small steam-turbine installations, it's essential to actively explore diesel-generator-heating installations, which will be widely used in the energy supply of agricultural sites and individual residential constructions.

A diesel-generator is a source of continuous power supply used where there is no possibility to use the central distribution networks. This device is an internal combustion engine (IC-engine) and an alternating current generator connected with a metal frame with a control panel and a fuel tank. It can be used for operation in various premises: from a large-scale construction to a small house or a cottage.

The developments of small and medium-sized businesses, as well as an increasing number of energy consumers – particularly in decentralized and remote rural areas – require the development of relatively cheap, compact, autonomous and multi-purpose energy resources. The above mentioned problems lead to a search for complex methods and efficient ways to convert heat energy with cogeneration of useful energy forms: electricity, heat and cold transformation, as well as chemical energy in a single thermal power plant or in the traction electric installation (TEI).

In such circumstances, the use of compact diesels – the generating heat and power plants (Figure 6.13) is the best solution for the following reasons.

– high efficiency coefficient as compared with other heat engines;
– possibility of power plant's adaptability to the specific needs of each customer;
– compactness and portability;
– flexibility regarding the used fuel;
– reliability and safety in operation and maintenance, etc.

An operational principle of a common diesel-generator is extremely simple and therefore effective. The generated energy as a result of fuel combustion produces mechanical work, which is used to generate electricity. However, in addition to electricity, diesel power generators also produce heat energy, and therefore at the assembly stage they are provided with an additional cooling element that prevents overheating.

The organic Rankine cycle (ORC) attracts interest in the area of the efficiency improvement of power plants to generate electric and heat energy.

The ORC process is similar to a thermodynamic cycle of a conventional steam turbine, in which a working body for a turbine's drive, the organic substances having a high molecular weight and a low boiling temperature are used instead of steam. Due to various operating bodies it's feasible to use the low-temperature heat sources in a wide power range (from a few watts to tens of MW of electric power in the same module). Today the ozone-friendly freons are developed and produced providing an opportunity to effectively use the heat from the sources with different initial temperatures. Consequently, the ORC generating plants are widely used in low-grade heat insulation systems.

Figure 6.13. Diesel-generator installations of small and medium capacities

The thermodynamic cycle in the ORC is carried out in the following way. An organic working body evaporates, when inputting heat from the source, in the evaporator. The steams of a working body while expanding rotate the axial turbine connected with a synchronous generator. After that, the steams giving up their energy condense in water or air heat exchanger-condenser. Condensate is delivered via a pump to the evaporator – the thermodynamic cycle is closed. The source of heat and a cooling substance do not have a direct contact with a working body or a turbine. This cycle is designed for a combined heat and electric energy generation (cogeneration). The application: geothermal power plants, boilers on any fuel; utilization of low-grade heat in the industry and independent power supply of private farms.

The advantages of the ORC technology and operation:

- a high overall cycle's efficiency coefficient (98 %), and electric efficiency coefficient (24 %) at varying initial temperatures [37];
- a low mechanical load on the turbine due to a low peripheral speed;
- no gear between the turbine and the generator due to a low speed of the turbine;
- no need for a water treatment system;
- no dropping erosion;
- a long-term autonomous operation is about 50 thous. h., a total service life is more than 20 years;
- an automatic operation regime and an easy start-up procedure;
- low maintenance requirements and ease of use;
- a low level of noise and vibration;
- good performance at a partial load.

Due to these advantages, the power plants based on the ORC technology are rapidly spreading around the world. At the present stage there are 62 installations in Germany, 32 in Austria, 23 in Italy, all in all there are up to 132 installations in Europe [37].

The ORC power plant is a modular construction containing all the necessary units (a turbine, a generator, heat exchangers, a pump of a working body, pipelines, and measurement instrumentations, an automation and control cabinet and so on.)

mounted on a common frame. Thus, transportation, installation and service are simplified.

The use of cogeneration installations with the organic Rankine cycle (ORC) allows exercising a combined generation of heat and electricity using peat-like pellets as fuel (Figure 6.14).

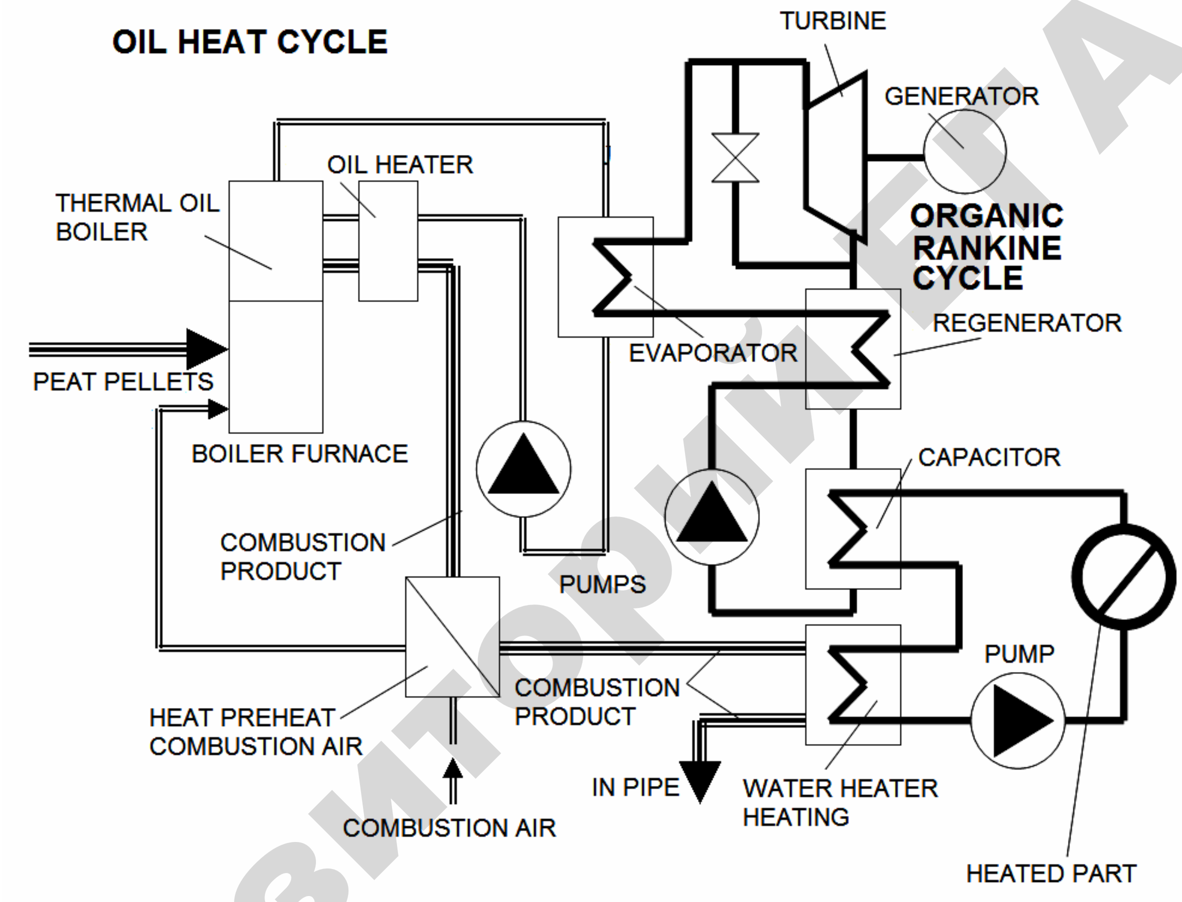


Figure 6.14. Cogeneration diagram with the use of the organic Rankine cycle (ORC)

The sphere of the modules' application running on the ORC is varied enough and includes different sectors of the national economy.

Let's give the example of the block-circuits of the ORC modules' application when producing pellets (Figure 6.15) and in the wood-processing factories when producing firewoods, corresponding to the Baltic standard, it means having a moisture content of no more than 20 % (Figure 6.16).

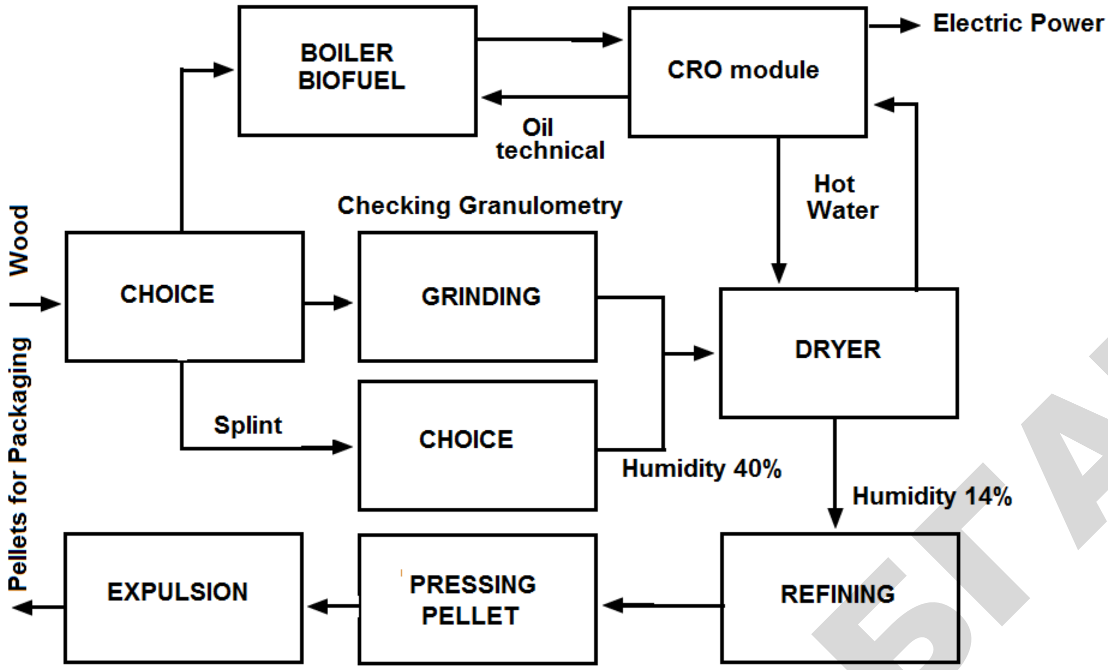


Figure 6.15. The ORC modules application when producing pellets

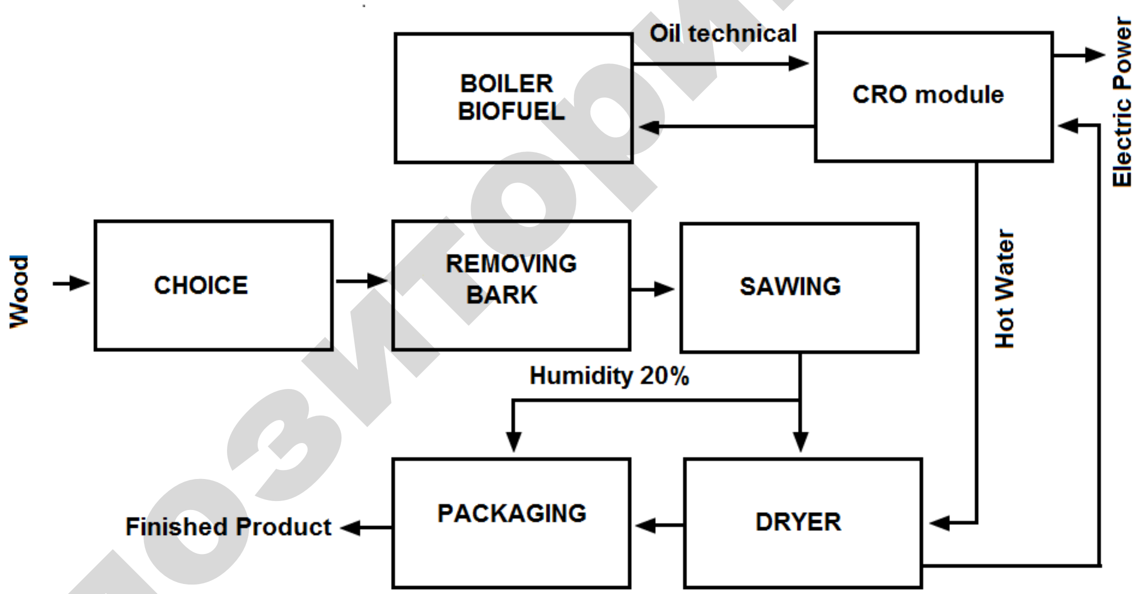


Figure 6.16. The ORC modules' application in the wood-processing factories when producing firewoods

7. Solar energy and wind energy in the systems of the agro industrial complex

Alternative and renewable energy sources are the sources of electric and heat energy using the energy resources of rivers, reservoirs and industrial drains, wind energy, solar energy, reducible natural gas, biomass (including wood wastes), sewage waters and solid industrial wastes [38].

In 2015, due to the increasing usage of local fuels and renewable energy resources the share of the country's energy resources in the balance of boiler and furnace fuels of the Republic of Belarus should be no more than 30 percent.

By 2016 it has been planned to introduce 162 MW wind power plants (WPP), and on condition that there is a sufficient amount of investment funds total electric capacity of the wind parks can reach up to 300 MW, and in Vitebsk and Grodno regions – up to 60 MW, and in Mogilev region – up to 50 MW.

Potential reserves of renewable energy resources (biogas, phytomass, solar energy, wind energy, geothermal, utilities wastes and crop production wastes) prevent from creating relatively large economically viable capacities in the power sector. Their usage is advisable in small local installations, the list of which is defined in the National Programme for the Development of Local and Renewable Energy Resources for 2011 – 2015 years. The usage amount in accordance with this program is estimated at about 600 thous. tons of oil equivalent.

Solar energy is regenerated by the sun: this is heat, radiation and natural cycles (wind, water flow, and the plants' growth, a driving force of which is solar energy). The total flux of energy emitted by the sun is 3,9·1026 J/s. Solar radiation is electromagnetic energy emitted by the sun.

Solar energy reaching the Earth's surface is scattered in different ways (Figure 7.1). Solar energy is clean, easy to use, cheap, flows constantly in abundance, and it has no negative impact on the environment, and can be used as a decentralized energy source.

The intensity of solar radiation reaching the Earth's surface depends on the degree of the atmospheric absorption, the latitudinal location of terrain, the sun's declination and cloudiness. Even on a clear day, about 13 % of the incoming solar radiation is absorbed by dust, water steam and other tiny particles suspended in the air.

Various technologies of the usage of abundant solar energy have been developed: from small power supply units for individual houses' systems to large-scale systems concentrating solar energy. These solar systems have one feature in common: they allow us to diversify the energy sources, to improve efficiency and ultimately to meet our energy needs in an environmentally friendly and efficient way.

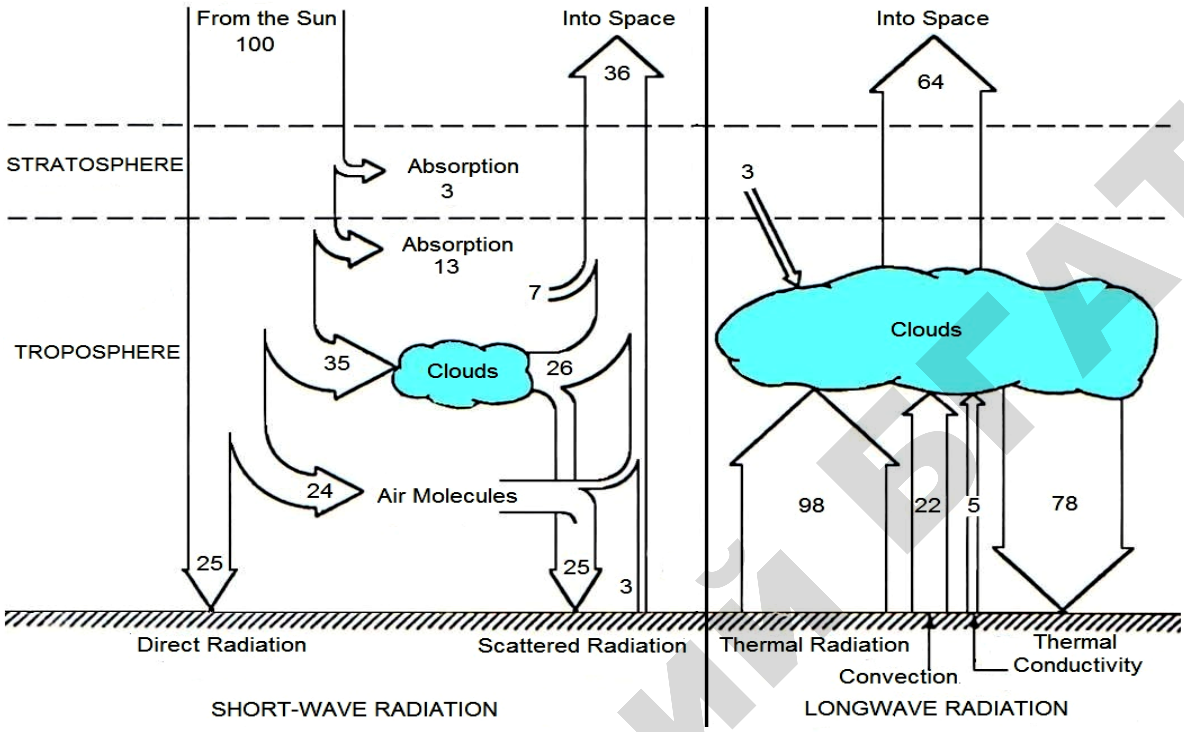


Figure 7.1. Heat balance of the system "Earth – atmosphere – space environment"

Depending on the application method, solar energy belongs to one of the two categories: active and passive. A solar collector is used in the conversion systems of active solar energy (Figure 7.2).

In its turn, active solar energy is divided into two categories: thermal and photovoltaic solar energy. Thermal solar energy is used in the heating systems, such as water and air heating, thermal food processing and drying, distillation and steam production. Technologies using thermal solar energy are used in the creation of solar water heaters, concentrators, plates and desalinators. Photovoltaic solar energy is used to generate electricity involving the usage of silicon elements to modify solar energy into electric energy, which can be used directly or by accumulating in the storage system.

An operating principle of the most common types of solar cells is based on the photovoltaic effect. The essence of this effect is in the potential difference appearance (or voltage) between the two layers of semiconductor material under light incidence on the two-layered material.

Solar modules are usually made of silicon treated in such a way that under light incidence there appear free electrons in it, creating an electric current. Currently, it is practically the only material used for a mass production of solar cells. In addition to it, gallium-arsenide (GaAs) is used to produce high-effective solar cells. The efficiency coefficient of such elements is up to 25–28 % under a concentrated solar radiation. The efficiency coefficient of special photocells used in space vehicles is more than 30 %.

Figure 7.2. A vacuous solar collector (solar collector)

The company HHVST is a famous manufacturer of solar batteries, it produces solar photovoltaic panels made of amorphous (thin-film) and crystalline silicon, corresponding to strict requirements of commercial and industrial organizations around the world (Figure 7.3).

Figure 7.3. A general view of solar photovoltaic panels

The peculiarities and benefits of solar batteries made of crystalline silicon:

– high-efficient solar cells of monocrystalline and polycrystalline silicon;
– an optimal combination of high quality raw materials and components;
– a lightweight anodized aluminum frame of the solar panel;
– a high reliability even in extreme weather conditions;
– capacity is up to 400 W;
– efficiency coefficient is 16 %.

In solar cells of this type one layer of silicon is used as a semiconductor. To produce this type of silicon, it must have a very high degree of purity, and hence the manufacture of these solar batteries is the most expensive. The reliability and the high efficiency coefficient of solar batteries of monocrystalline type are their main advantages.

The application fields of such batteries:

– power plants connected to the general power line;
– solar systems of street lightning;
– solar systems of home lightning;
– solar modules of energy supply;
– other autonomous systems;

– a system of pressure water supply.

The term passive solar energy is used when an architectural design, natural materials and absorbent structures of a building are used as the energy-efficient system. The building functions as a solar collector and accumulator of solar energy, which allows the designer to reduce a necessity of solutions for the external energy supply: lighting, heating and cooling, water supply and so on.

The main task of a passive solar design is to create such architectural and building systems that trap the sun's heat, direct it deep into premises, accumulate and return at the right time, significantly reducing the heating costs. There are various methods of a passive use of solar energy to heat buildings. A device of the light-transparent heat insulation and the built-in or adjoined greenhouses and conservatories are considered to be the most common of them. A combined use of multiple systems is thought to be effective.

There are 8 principles of a solar design of such constructions.

Principle 1. The house should be placed so that the walls and the roof were oriented to the south with a deviation of no more than 10–20°. The landscape's features must be taken into account: trees, buildings, terrain features that can protect the house from harsh weather conditions or the wind in winter, or hide it from a too bright sun in summer.

Principle 2. In developing the design a one-year cycle is taken into consideration. Before constructing it's necessary to visit the site of a future house several times throughout the year, to study the position of the sun and wind.

Principle 3. Reliable heat insulation and hydro insulation must be used. The entrance is built up according to the principle of a vestibule with two doors.

Principle 4. The windows are used as solar collectors and devices for cooling. A vertical oriented to the south glazing is particularly effective for collecting solar heat in winter. The curtains or blinds made of insulating material are used to minimize heat losses at night in winter and prevent from overheating in spring, summer and autumn.

Principle 5. It's necessary to bear in mind that the house that has been glazed several times can overheat.

Principle 6. It is necessary to calculate an additional heating system correctly.

Principle 7. An air exchange should occur through special holes in the outer walls with the installed ventilators in the kitchen and bathroom, and not through the slits in poorly insulated doors and windows.

Principle 8. A good organization of air flows in the building is the basis for the dissemination of the resulting heat in the premises due to a natural convection.

For Belarusian conditions, during a forecast period (until 2020), the production component of electricity using solar energy will be practically not obvious. The main directions of solar energy use will be solar water-heaters and various solar plants for intensification of the drying processes and water heating in the agricultural production. In addition, an active and passive solar energy possess all the prerequisites to be used while designing the agricultural settlements and remote small objects in agriculture.

The simplest and cheapest way to use solar energy is to heat domestic water in flat solar collectors (Figure 7.4). Using solar energy, solar systems can annually save traditional fuels:

- 75 % – for hot water supply (HWS) for a year-round use;
- 95 % – for HWS in a seasonal use;
- 50 % – for heating purposes;
- 80 % – background heating purposes.

It's necessary to keep in mind that each system is unique; the percentage of energy savings while using a solar system must be calculated.

Figure 7.4. A block of flat solar collectors, consisting of two modules

Devices with vacuum solar collectors are more complicated. On sunny summer days, the operational difference of good flat and vacuum solar collectors is almost imperceptible. However, at a low ambient temperature the advantages of vacuum collectors become evident. Also, even in summertime there is a difference between maximum temperatures of water heating in collectors. If for flat collectors a maximum temperature does not exceed 80–90 °C, than in vacuum collectors the heat carrier's temperature can exceed by 100 °C. On the one hand, it requires a continuous heat removal from a vacuum collector so that it does not boil. However, on the other hand, in the systems with flat collectors there is a problem of bacteria growth and other microorganisms (it's warm and humid there), which does not exist in the systems with vacuum collectors. Typically, the systems with flat collectors are used seasonally, from spring to autumn. In wintertime, the performance of the systems with flat solar collectors falls due to heat losses to the environment. A sunny vacuum collector provides a gathering of solar radiation in all weather conditions, almost regardless of the outside temperature. The absorption energy coefficient of such collectors is 98 %. Insulation in the form of a vacuum avoids heat losses. The effectiveness of various collectors is shown in Figure 7.5.

Due to the high heat insulation vacuum solar collectors work very effectively at low ambient temperatures. The advantage of vacuum collectors (in comparison with flat collectors) is observed at the air temperature below 15 °C, there is no alternative to vacuum collectors at subzero air temperatures.

Solar heat plants on the basis of vacuum collectors can be used both for hot water supply and house heating. Meanwhile in summer, hot water can be completely obtained from a solar heater. In other periods of the year approximately 60 % of hot water can be obtained due to solar energy.

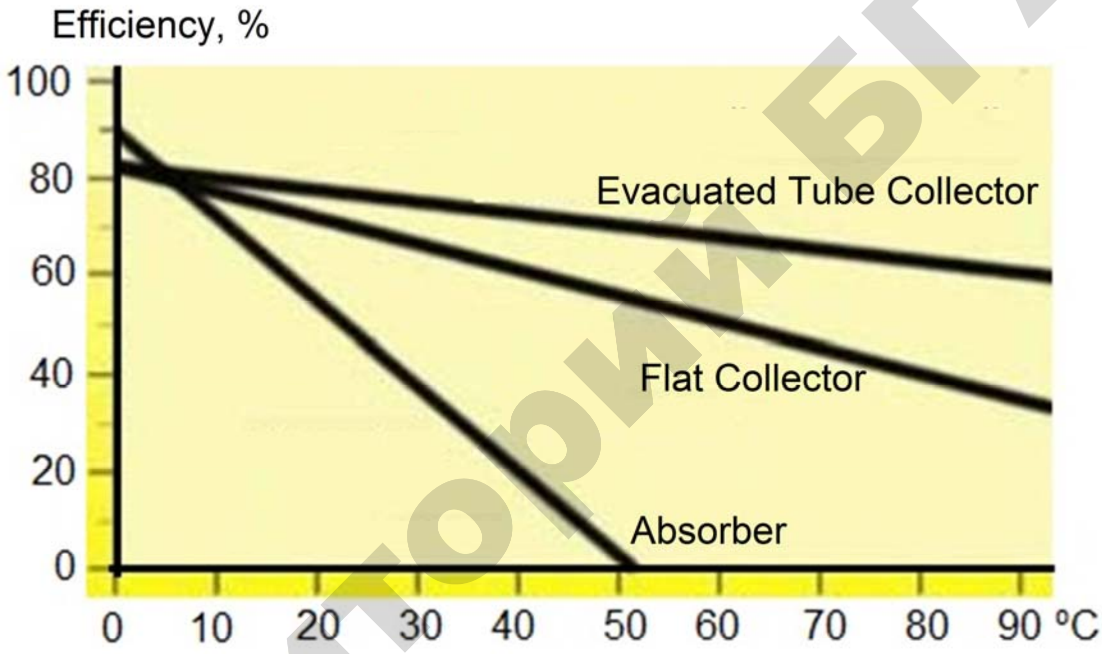


Figure 7.5. The EC dependence of various solar collectors on the temperature difference inside the collector's pipes (heat carrier) and the environment

Frequently there is a question whether it's feasible to heat a house due to solar energy. Unfortunately, in the Republic of Belarus a significant share of a solar heating in the heat balance is out of the question. However, a solar heat plant based on vacuum solar collectors can successfully cope with the task of maintaining a minimum set temperature indoors in spring and autumn.

Usually it's recommended to calculate a solar heating system based on hot water supply (HWS). Thus, it is possible to double the amount of collectors in order to ensure the HWS supply in spring and autumn and have a significant addition to the heat generation in winter. If the amount of collectors is increased in 3–5 times, it’s possible to feel the solar heat addition during the heating balance in the offseason.

The calculations of this system are made by special organizations, but for the first approximation they can be performed independently using the diagram (Figure 7.6).

How to arrange solar collectors correctly? Solar collectors must be oriented if possible to a south direction. However, without a significant loss of performance, it’s permitted to deviate from the south to 30°. For photovoltaic panels it’s permitted to deviate to 45° without a significant deterioration. The exceedance of these recommended figures can greatly impair the efficiency of a solar heat or electric supply system.

It’s usually recommended to place solar collectors and solar batteries for an all-year round usage at an angle to the horizon, which is approximately equal to the location latitude. If the system is exploited mostly in summer, it is necessary to reduce this angle by 15°, if mainly in winter – increase by 15°.

If a location’s latitude is more than 60°, than the collector can be installed vertically (a problem with snow is also solved – it usually does not stay longer on vertical surfaces). If a vacuum collector is installed at an angle less than 80°, then there should be a free space under the collector for the falling snow from it.

Usually in our conditions, collectors (both flat and vacuum) and solar batteries, installed directly on the roofs, as a result they are covered with snow and ice during practically the whole winter, so they actually do not work. If it is important to ensure the operation of the solar energy supply systems in winter, it is recommended to install them either vertically or at an angle of about 60°, but with a free space provision under collectors where snow and ice can fall down from the collectors.

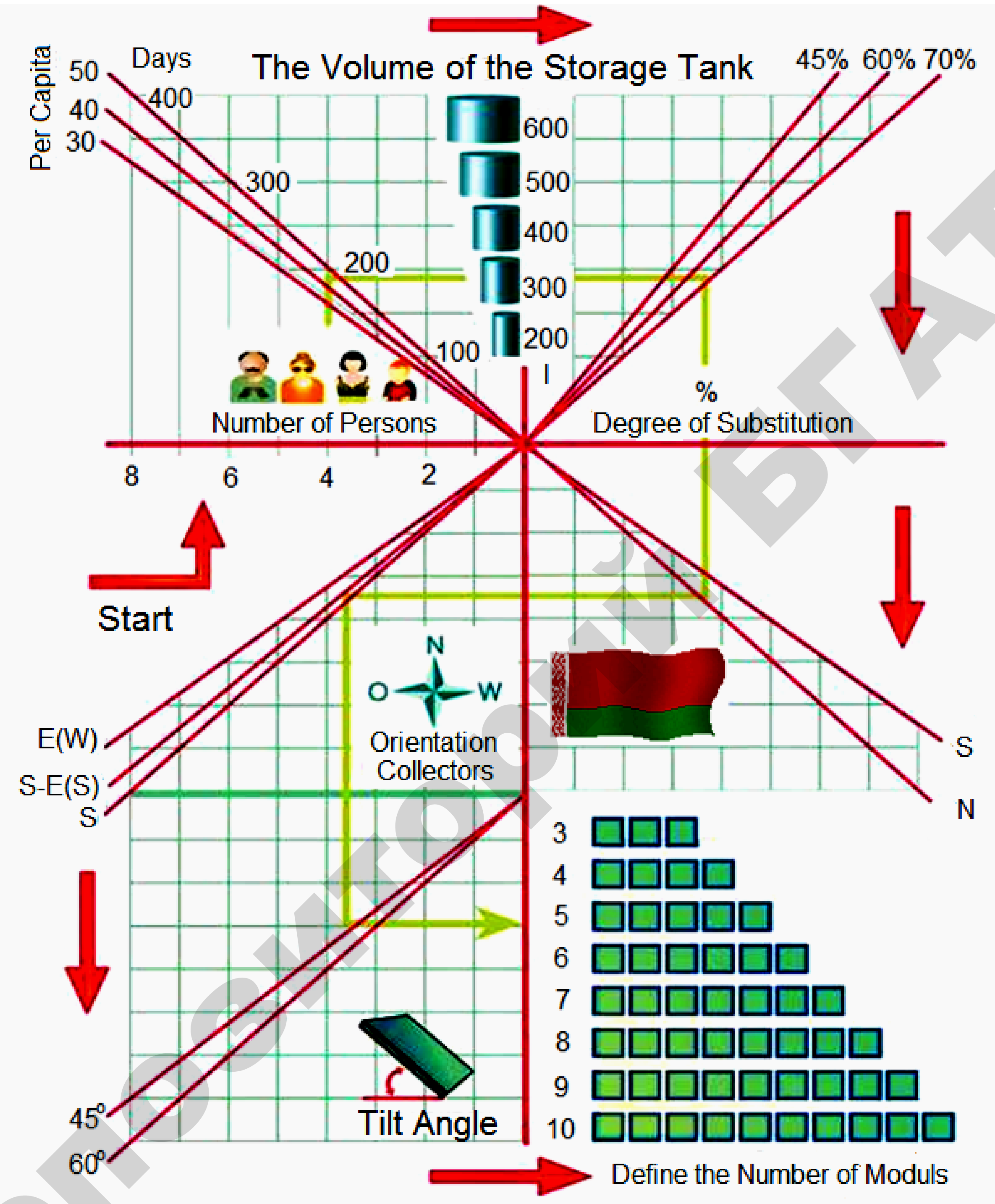


Figure 7.6. The diagram for calculations of solar system

One of the most simple, common and inexpensive vacuum tubes for solar water-heating plants is shown in Fifure 7.7. It is used in the systems with an open

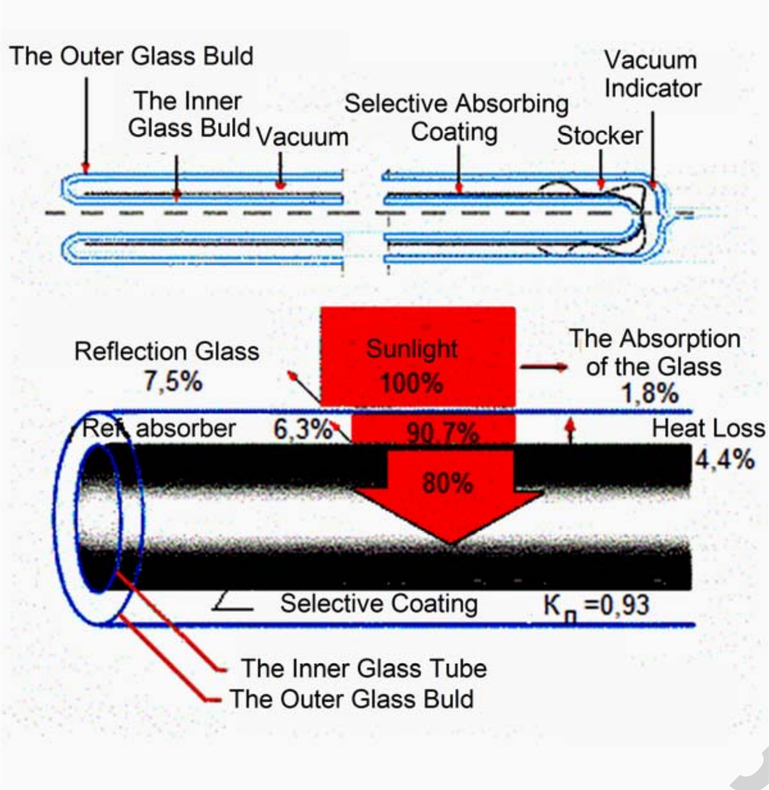


Figure 7.7. The simplest device of a vacuum tube for solar collectors

loop or low pressure. In the systems where a heat carrier is water, it is recommended to use at continuous temperatures not lower than –30 °C. Some other modifications are made on the basis of this tube. Such tubes are an invention of the Chinese manufacturers and are used only in the products of Chinese firms. The main characteristics of solar collectors are presented in Table 7.1.

Table 7.1. Collectors' technical characteristics

Parameter	Value
Tubes' length, mm	1500 (1800)
Tubes' outside diameter, mm	47 (58)
Maximum temperature, °C	250
Tube's material	Borosilicate glass (3.3)
Collector's exploitation time, years	15

A vacuum tube with copper channels, which is developed on the basis of the above described tube for the closed active systems, is the most improved solar collector's device. A contact plate and a copper tube are inserted inside. The characteristics are similar (see Table 7.1).

Modern solar collectors of the improved characteristics are devices in the form of vacuum tubes with a heat rod (a heat tube). Such devices (Figure 7.8) consist of a tube (Figure 7.7), inside of which a contact plate and a heat rod are inserted – a heat tube. This tube is resistant to freezing and workable without damage up to –50 °C. Inside of the rod there is a small amount of antifreeze substance at low pressure, that's why liquid evaporation begins when the temperature inside of the tube reaches up to +30 °C. This is a more advanced type of the tube, which can operate at low temperatures and plumbing pressure.

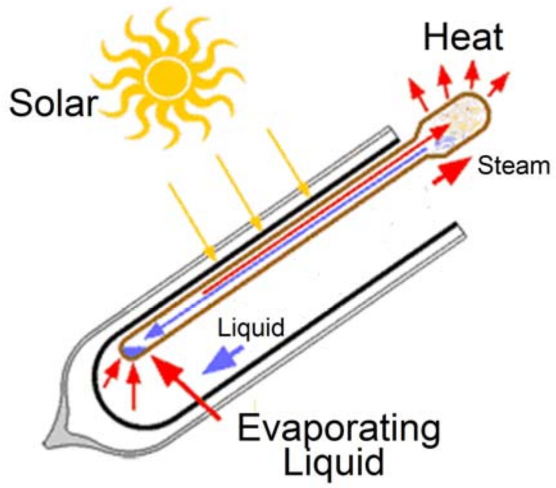


Figure 7.8. A vacuum tube with a heat rod (heat tube)

An improved version of a vacuum tube with a heat rod. Inside of a transparent vacuum tube a flat absorbing plate is inserted, and it's connected with a heat rod. It has a larger diameter (70 mm), and accordingly, the area of an absorbing surface. Due to a big absorption area transit time to the heat emission regime may be only 2 minutes.

The systems of solar hot water supply with a heat carrier's passive circulation (Figure 7.9) are often applied in practice of the individual houses' construction. Such systems are made single-circuit and double-circuit.

The operation of a single-circuit thermosiphon system for a direct water heating is carried out in the following way (Figure 7.9a). Solar radiation passes through a collector's transparent coating (glazing), heats its absorbent panel and water in its channels. Upon heating water density decreases, and a heated liquid begins to move into the collector's upper point and further along the conduit – into a storage tank. In the storage tank the heated water moves to the upper point and colder water occupies the lowest point of the storage tank; water stratification depending on the temperature is observed. Cooler water from the lowest point of the storage tank moves to the collector's lowest point through the conduit. Thus, if there is sufficient solar radiation, a constant circulation is set in the collector circuit, the speed and intensity of which depend on the density of a solar radiation flow. Gradually, during daylight hours, the whole storage tank is heated, provided that a water selection for the usage should be made from the hottest water layers, which are located at the top of the storage tank. Usually this is done with the cold water supply into the storage tank at the bottom under pressure, which expels the heated water from the storage tank.

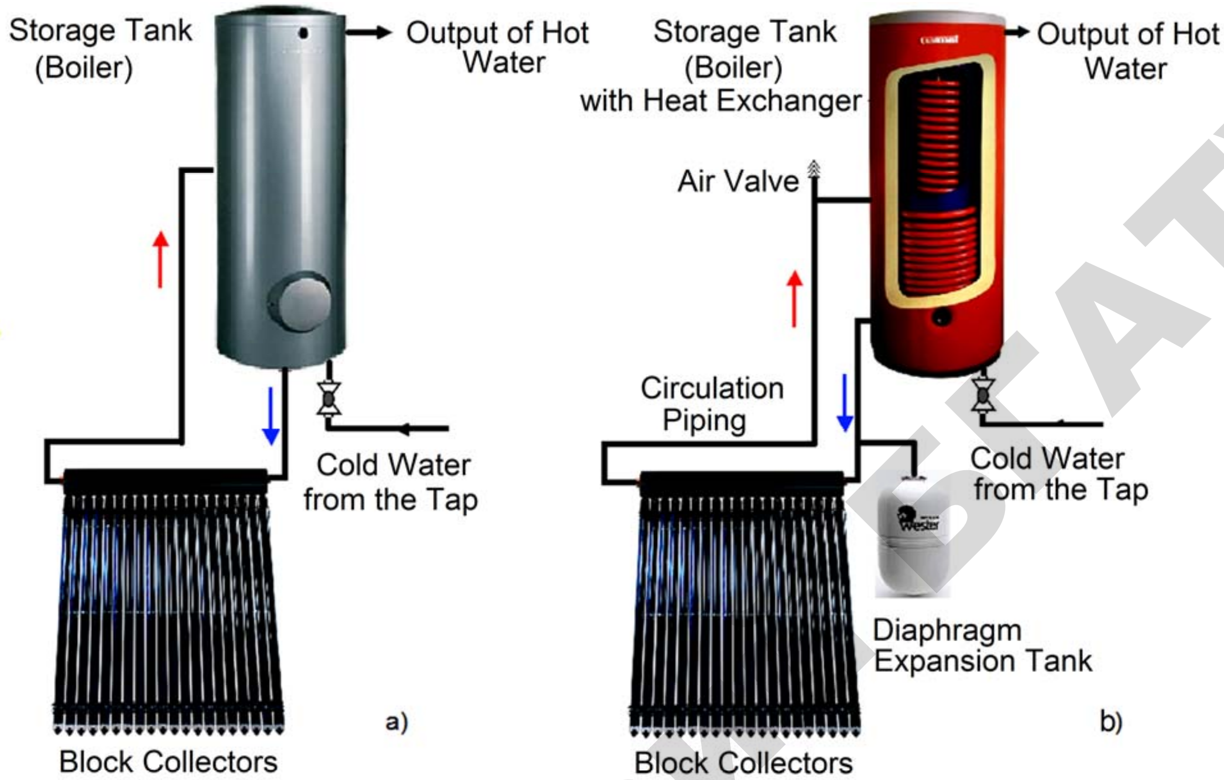


Figure 7.9. Principal designs of the solar hot water supply systems with a passive heat carrier's circulation: a) single-circuit; b) double-circuit

A distinctive feature of such systems is that in case of a thermosiphon system the lowest point of the storage tank must be located above the collector's upper point and no more than 3–4 m from collectors, and in case of a heat carrier's pump circulation the location of the storage tank can be arbitrary.

The operation of a double-circuit thermosiphon system (Figure 7.9b) is identical to the operation of a single-circuit system, but in the system there is a separate closed collector's circuit consisting of collectors, conduits and a heat exchanger in the storage tank. This circuit is filled with a special heat carrier (as a rule, non-freezing). By heating the heat carrier in the collector it enters the heat exchanger's upper part, gives up heat to the water in the tank and cooling moves down into collectors, performing a constant circulation if there is solar radiation.

A complete tank's heating occurs gradually during the daylight hours, but because a water selection to the consumer is made from the most heated upper layers, the usage of hot water is possible until a complete heating.

A distinctive feature of a double-circuit thermosiphon system is that the lowest point of the storage tank must be located above the collector's upper point and not more than 3–4 m from collectors, and in case of a heat carrier's pump circulation the storage tank's arrangement can be arbitrary.

In the systems with a forced circulation (Figure 7.10) a circulation pump is included in the collector's circuit, which enables to install the storage tank in any part of the building. The direction of a heat carrier's movement must coincide with the direction of a natural circulation in the collectors. A pump's turning on and off is made with an electronic control module, which is a differential control relay, comparing the sensor's temperature readings, installed at the exit of the collectors and in the tank. The pump is activated if the temperature in the collectors is above the water temperature in the tank. There are modules that enable to change a rotational speed and a pump output, maintaining a constant temperature difference between the collectors and the storage tanks. The systems with a heat carrier's active circulation are usually double-circuit.

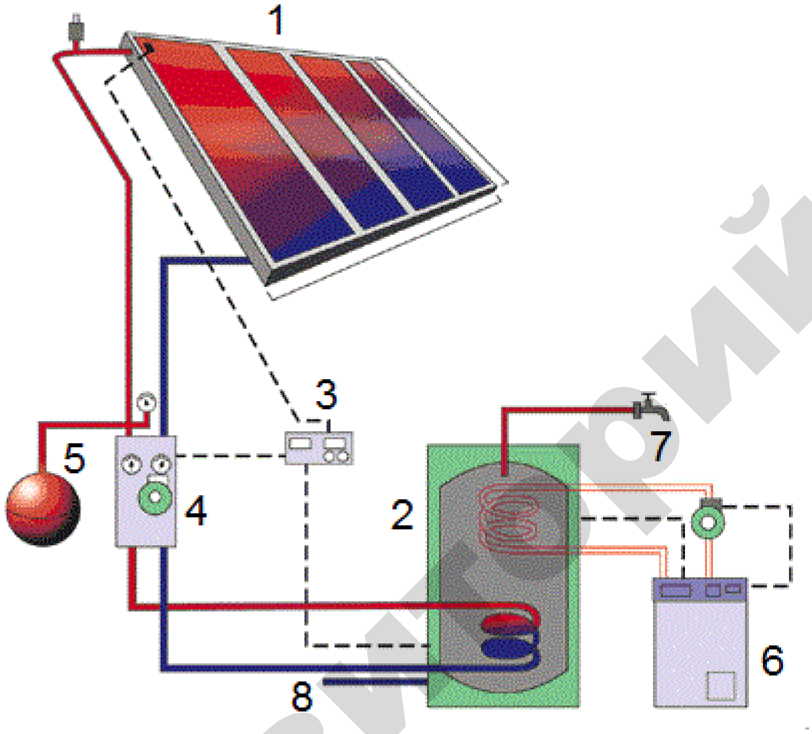


Figure 7.10. The circuit of a solar hot water supply with a forced circulation:
1 – collector; 2 – boiler; 3 – control panel;
4 – pump; 5 – expansion tank; 6 – source of additional heating;
7 – hot water outlet;
8 – cold water inlet

With regard to the agroindustrial complex of the Republic of Belarus, from 2007 the advanced farms have been trying to use solar collectors on farms (Figure 7.11) when keeping cattle on a deep litter. In this case, systems with the premises' heating are not used (see section 4), which entails special requirement for the system of animals' feeding with warm water 22–24 °C.

а)

б)

Figure 7.11. Placement of vacuum solar collectors at roofs of cattle keeping farms (drinking water heating system for animals):
a – JV "Unibox"; b – SNOV Agricultural Production Complex

Experience has proven that such systems of water heating are effective throughout the year, and in summer they can serve to meet the needs of the HWS for technological processes on the cattle farms and ensure industrial needs of the operating personnel.

The only operational requirement for solar collectors in summer at a maximum solar activity is an intense hot water removal (hot, up to 60 °C) or the covering of the solar collector's surface part a with the tarpaulin to prevent from a heat carrier's boiling in the vacuum heat tubes.

The usage of absorption refrigerating machines with solar collectors is perspective; they solve all the problems of the solar system exploitation and provide an additional cooling function, as required for cattle keeping farms in summer.

The company HHV SOLAR represents Soltor-7.2 – a conceptual solar mobile photo-mounting (Figure 7.12) capable of capturing solar energy, converting it into electric energy of alternating current and charge an on-board accumulator battery to provide power supply at anytime, anywhere.

Figure 7.12. A mobile installation with a photoelectric converter to power self-contained devices in places with a limited power supply

The peculiarities and advantages:

– ecologically clean energy; fossil fuels are not required for the installation's operation;

– reduction of the carbon footprint: electricity generation without releasing pollutants;

– a silent operation: in a process of electricity generation no moving mechanical parts are involved;

– solar panels are easily turned around due to an action of a force actuation device;

– a compact and durable construction: can be installed in any place at any time;
– one person operation.

In the world ranking of the countries promoting wind energy at the own territories Belarus held the 67th place in 2010, although it has wind energy resources that are sufficient to provide 10–20 % of the required electricity in the country [18].

Belarus does not have its own fuel and energy resources. In this regard, it is extremely important for Belarus to include secondary energy resources and renewable energy sources into the fuel and energy balance, one of which is the wind.

Wind energy, like any other branch of economy management, must have three essential components that ensure its functioning:
– wind energy resources;
– wind energy equipment (wind turbines);
– developed wind-technical infrastructure.

1st component. Wind energy resources in Belarus are almost unlimited for wind energy. In the country there is a developed centralized power line and a large amount of free spaces not occupied by business entities. Therefore, the placement of wind turbines and wind-power stations is due to the right placement of wind energy equipment at the suitable for this territory.

2nd component. The possibilities to acquire foreign wind equipment are practically limited.

3rd component. The absence of infrastructure for design, implementation and operation of wind-equipment and, accordingly, a lack of experience and skilled staff, all the stated above can only be overcome in the course of an active cooperation with the foreign representatives of the developed wind energy infra-structure.

As the wind's characteristics in the continent differ from the wind's characteristics of coastal areas and near a coastal area, the characteristics of the respective wind turbines (initial rotation speed, the achievement speed of nominal rating power, etc.) are also different.

Thus, the well-proven wind turbines in operation of an intercontinental base of several German companies begin to work at the wind's speed of 3,0–4,0 m/s and achieve nominal rating power at speeds of 10–13 m/s. Therefore, the development of wind energy in Belarus must be carried out, focusing on wind turbines of a foreign production of an intercontinental base.

A zonal distribution map of the annual-average wind's background speeds in Belarus is presented in Figure 7.13 [43]. It identifies the prospective zones of the wind turbines' usage, however, the demand for electricity in a particular region and the electric networks' readiness to adopt additional electrical resources should be necessarily taken into account.

According to the world practice, such wind turbines as B12 and B14 correspond to nominal power to 1 kW to 1,5 MW. The wind turbine B12, for a continental base in Europe, has a nominal operating range of the wind's speed at the center of a wind engine from 12 to 14 m/s. The types of the wind turbines B6, B8, B10 are identified according to the wind climatic zones, typical of the plains and hilly territories. For the wind turbines B6, B8, B10, at the axis's level of a wind engine, the nominal operating wind's speed is respectively distributed in the range of 6–8 m/s, 8–10 m/s and 10–12 m/s. The activities focused on assessing the technical wind energy resources of Belarus are made jointly by "Vetromash", Belarusian Research and Design Republican Unitary Enterprise "Belenergosetprojekt" and the State Committee for Hydrometeorology (see Table 7.2 and 7.3).

Assured development of the utilizing wind energy from 7 % of the territory of Belarus will be 14,65 billion kW·h. The use of areas with a high wind's activity ensures the energy production of wind turbines up to 65–7,5 billion kW·h with cost recovery in the next 5–7 years.

These maps (Figure 7.13) are the main part of a wind power atlas of Belarus, and sufficiently justify on regional grounds the possibilities of a practical implementation of the wind turbines' and wind-power stations' construction in the country as a whole and in each region.

In Belarus 1840 sites have been identified for the wind turbines' and wind-power stations' construction with energy potential of over 200 billion kW h [43, 44] [5].

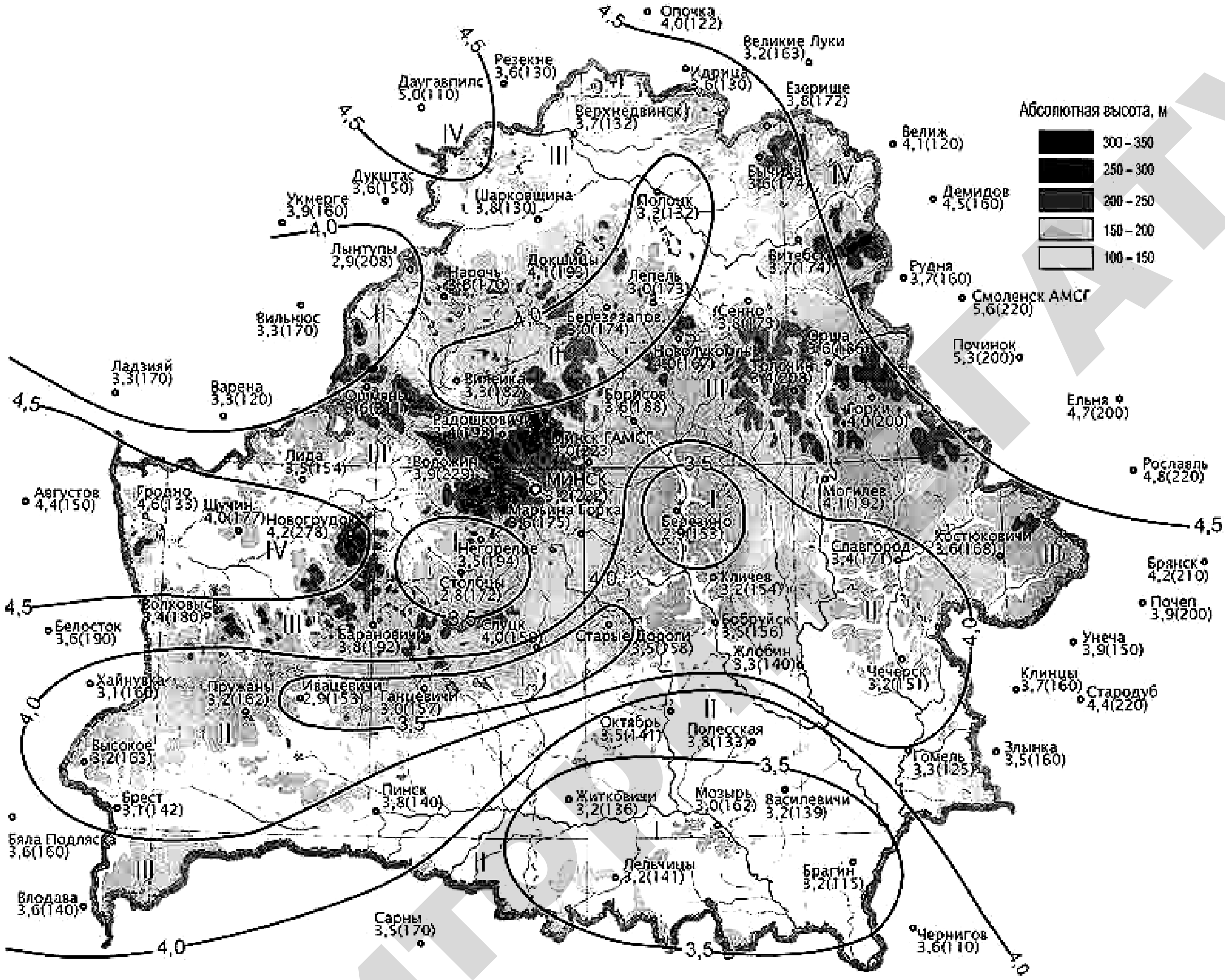


Figure 7.13. A zonality distribution map of the average annual wind's background speeds in Belarus: I, II, III, IV – zones of wind's background speeds correspondingly zonally: I till 3,5; II 3,5–4,0; III 4,0–4,5; IV more than 4,5 m/s; 4,2 (163) – wind characteristics of meteorological stations, where 4,2 is a wind's average-background speed, m/s; (163) is an absolute altitude of meteorological stations' location, m

[5] *The range of hills with the height from 20 to 80 m with a wind's background speed of 5 m /s or more, on which from 5 to 20 wind turbines may be built.*

Table 7.2. Wind energy resources of the territory of Belarus [43, 44]

Region	Exploited territory, thou.km^2	Zone number	Zone territory, thou.km^2	Energy generation, billion kWh		
				Maximum in a zone	Utilizing wind energy resource	
					100 %	7 % for 10 years
				CWER	TWER	EWER
Brest	14,9	II	10,9	23,51	20,78	1,45
		III	3,1	11,74	9,04	0,63
		IV	0,9	6,11	4,06	0,29
		Total		41,36	33,88	2,37
Vitebsk	12,5	II	1,0	2,41	2,02	0,14
		III	4,2	20,11	16,43	0,12
		IV	7,3	53,13	35,33	2,47
		Total		75,65	53,78	2,73
Gomel	12,4	II	1,4	3,02	2,67	0,19
		III	8,5	32,43	24,96	1,75
		IV	2,5	16,30	10,84	0,75
		Total		51,75	38,47	2,69
Grodno	11,2	II	6,0	12,93	11,43	0,80
		III	2,9	11,09	8,29	0,58
		IV	2,3	15,22	10,12	0,71
		Total		39,24	29,84	2,09
Mogilev	12,4	II	10,5	22,74	18,07	1,31
		III	1,9	7,25	5,58	0,39
		Total		29,99	23,65	1,70
Minsk	13,9	II	9,9	25,42	22,48	1,68
		III	1,3	4,84	3,73	0,26
		IV	2,7	19,93	17,62	1,23
		Total		50,19	43,83	3,07
Total in Belarus:	77,4	II	39,7	90,03	77,45	5,47
		III	21,9	87,46	68,03	3,73
		IV	15,7	110,59	78,02	5,45
		Total		288,08	223,50	14,65

Please note:

1. CWER – complete wind energy resource, which is based on calculations with the use of zonal indexes of wind's background speeds to a certain bearing with the wind turbine's height to the increase ration (1,25), including the length of operation in a nominal regime (≈3000 h).
2. TWER – technical wind energy resource, which is based on the terrain's peculiarities of the region's territories taking into account the wind turbine's operational coefficient – electromechanical (0,94) and simple (0,93).
3. EWER – economical wind energy resource is determined while planning the wind energy development of Belarus.

Table 7.3. Characteristics of wind energy resources based on regional attributes [43, 44]

Indicators	Regions and their altitude, m				
	100—150	150—200	200—250	250—300	More than 300
Class of sites	I	II	III	IV	V
Area size of regions, km^2	91 741	99 421	13 907	2 283	208
Annual average wind's background speed, m/s	3,8	4,2	4,5	4,9	5,3
Annual average wind's speed at a height of 10 m, m/s	4,5	4,9	5,4	5,8	6,2
Annual average wind's speed at a height of 70 m, m/s	6,5	6,8	7,3	7,9	8,2
Calculated wind's speed (for wind turbines – nominal)	10,4	10,9	11,7	12,6	13,1
Wind current at a height of 10 m, BW/m^2	171	196	243	308	344
Total area for wind turbines, km^2	18348	19884	2781	457	42
Types of wind turbines	V6, B8	V8, V10	V10, V12	V12, V14	V14
Total area of wind turbines on the sites, MW	38 530	47 722	8 065	1 645	176
Annual output of wind turbines (TWER), billion kWh	115,6	143,2	24,2	4,9	0,5
Installed capacity of wind turbines with the 40th wheel, MW	0,33	0,38	0,47	0,59	0,66
Design number of wind turbines with the 40th wheel and N=500 kW on the sites [6] pcs.	165133	178957	25032	4109	378

Please note:

1. Distribution of the characteristics of wind energy resources has been carried out on a regional basis, assessed with the location's relief.

The most effective use of the modern foreign wind equipment is on the territory zones with annual average background speeds not lower than 4,5 m/s on the hilly terrain (a pay-off period of wind turbines at an average annual wind's speed of 6–8 m/s will be of about 5 years). These regions include: high elevation terrains of the most part of the north and north-west of Belarus, a central zone of Minsk region including the adjacent west regions, Vitebsk Uplands.

According to wind energy potential, only in Minsk region, there are 1076 of construction sites to be located on each of them from 3 to 10 wind turbines of a

[6] *Wind turbines on the site of 1 km^2.*

continental-base, powered up to 1 MW. The average annual production of only 10 % of these wind turbines, in the statistical operational time distribution in a nominal regime from 2 500 to 3 300 h in a year for the plants' lifetime, is about 2 676 million kW·h [44, 45].

The reformation of the Belarusian energy system is expected to be implemented in three stages over the 2010-2015 [46] [7]. According to this document, the reformation purpose of the Belarusian energy system is to create a national wholesale electricity market.

In the first stage (2010–2011) the Republican Unitary Enterprise "High-voltage electric networks" has been created, and also the development of a statutory legal base of the energy system's functioning in a new economic environment has been carried out. The enterprise's main objectives are the exploitation of high-voltage electrical networks, power transmission, an operational and dispatch management of an interconnected power system.

In the second stage (2012–2013) the Republican Unitary Enterprise "Belgeneratsiya", has been created, the structure of which includes the largest power plants.

In the third stage (2014–2015) a reformation process of the Belarusian energy system must be completed, creation of a wholesale electricity market and conditions for the efficient investments' attraction.

The implementation of such structural reforms of the Belarusian energy systems helps to solve many problems. The market structures must be formed and a national wholesale electricity market must be organized, the transparency of costs at all the stages of production, transmission, distribution and sale of electric and heat energy must be ensured.

The proposed alternative innovative scenario is supposed to reduce gas consumption in the energy sector by 2020, almost by as much as a half: from the current 18,5 billion m3 to 9,3 billion m^3. The development of wind energy, the use of biomass and production of biogas are viewed as the most significant alternatives

[7] *This is stipulated by a development strategy of energy potential of Belarus, approved by the Government.*

of nuclear power. According to the experts' data, the construction of 3,5 thous. of wind turbines with capacity of 2 MW each, will allow producing the same amount of electricity, as the two power-generating units of the planned to be constructed NPP.

It will require 7 billion dollars of investments, including the wind turbines' preparation for exploitation, which is less than 9 billion dollars that are necessary for a nuclear power plant. The wind turbines' construction cycle is less than a year, that's why it's possible to quickly regulate the introduction of wind turbines' capacities, depending on the energy consumption dynamics [46].

Five different wind turbines have been in operation over the past ten years in the Republic of Belarus:

1. A wind turbine "Nordex 29/250": capacity – 250 kW; commissioning – 2000.

2. A wind turbine "Jacobs 48/600": capacity – 600 kW; commissioning – 2001.

Both the plants are located in the village Zanaroch, Myadel district, Minsk region, they are being exploited by the organization "EkoDomStroy" in the framework of a humanitarian programme ICPO "EcoDom" (in coordination with the Department of Humanitarian Administration Affairs of the President of the Republic of Belarus) as a result of the implementation with the foreign partners' assistance. At the present moment the installations are in operation.

3. A wind turbine "Wind Turbine–200 kW": capacity – 200 kW (3 energy-generating units of 77 kW, produced by Ltd "Aerolla"); commissioning – 26.05.2008; place – "Svityazanka 2003", Korelichi district, Grodno region.

4. A wind turbine "Wind Turbine–250": installed capacity – 250 kW (produced by Ltd "Aerolla"); type – rotary; place – The international innovation environmental park –"Volma"; state: under modernization with a capacity increase up to 500 kW. Currently it is used only for training or demonstration purposes.

5. A wind turbine "Wind Turbine – 6": capacity – 6 kW (produced by Ltd "Aerolla"); place – The international innovation environmental park "Volma"; for the operational time (1,200 hours) it generated about 1,100 kW·h. Status: in operation, provides domestic needs.

The government of the Republic of Belarus supports the development of alternative energy. For example, a target state programme has been adopted, according to which the share of local fuels and alternative energy sources must be increased by 25 % in the energy balance by 2012. In the first stage a lot of attention is paid to the use of coal, peat and wood. The main stimulation directions of the new sites' construction, operating on local fuels – "Belenergo" electricity procurements, generated by such companies to raise tariffs. For the first 5 years of their operation it has been decided to buy electricity in 1,3 times more expensively than normal tariffs.

Over the past six years, the share of local fuels has increased significantly – from 5,3 % to 21,7 %, which has reduced the share of the imported fuel and energy resources of the housing and public utility sector from 94,7 % to 78,3 %.

By 2020 Belarus is determined to reduce the energy consumption of GDP up to 210–220 kg of oil equivalent per $1,000 of GDP and reach the level of Sweden on this indicator. In 2015, GDP energy consumption should be reduced by at least 50 %, in 2020 – no less than 60 % compared with 2005.

The issue of wind energy development in Belarus is the issue concerning not wind potential, but this is a matter of economics and energy policy. Two centuries ago it was hard to find a Belarusian village without a windmill. The plants were stationary and mobile: floating mills "vodyaki" and mobile "windmills" were widely used. In winter these "vodyaki" were set up in the quiet inlets on the side from the fairway. They were produced for the own needs and "for export" to Ukraine and Russia. These plants did not require dams and did no harm to the environment, as opposed to the dams. Therefore, a recent opinion on the wind energy development in Belarus, which lacks prospects among the persons who are responsible for making decisions and experts on traditional energy, does not correspond to a historical reality.

The amount of sites for wind turbines, of course, is more than 1840, but they should be chosen not only according to the speed of a wind flow, but also taking into account the networks' existence and capacity in an immediate vicinity of the site.

The appearance in the international market of wind turbines with capacities of 1,5–2 MW of a continental base (height is 90–110 m) basically changes the prospects of the wind power development in the country.

In Belarus in 2014–2018 wind parks with total capacity up to 300 MW can be built. This is stated in a Development strategy of energy potential of Belarus, which has been approved by the Council of Ministers №1180 and covers the period until the end of 2020.

The presentation of the first wind turbine in Belarus with capacity of 1,5 MW ("HEAG HW82/1500", a pilot project) was held in Grodno region, in April 2011. The participants of the presentation were representatives of the Chinese company HEAG, the Ministry of Energy of the Republic of Belarus, "Belenergo", the Republican Unitary Enterprise "Grodnoenergo" and local authorities. A wind turbine is located in the village of Grabniki, Novogrudok district. The height of the plant's location is above the sea level, about 320 m. The length of each of the three blades of a wind wheel is about 40 m, a mast height is 81 m. The equipment's weight is about 200 tons, the gondola's weight is 65 m. The manufacturer is the Chinese company "HEAG". The plant's average annual electricity generation in Novogrudok district is approximately 3,8 million kW h, which corresponds to the fuel equivalent economy of about 1,1–1,25 thous. tons. The total project cost is estimated at 8–9 billion Belarusian rubles [46].

According to a site's survey near the village of Grabniki it's possible to locate here a wind park of seven or eight wind turbines. The total estimated average annual electricity generation of such a wind park will be about 25–30 million kWh.

In conclusion, it should be noted that implementation effectiveness of wind turbines can be estimated on the basis of a payback period:

$$T = \frac{C_c}{(1-Z)C_A K_i u 8760},$$

where C_c – capital costs (Table 7.4), euro/kW;

C_A – electricity tariff, euro/kW·h;

Z – annual operating costs (they are on the basis of the existing reference data in the limits of 20 %, equal to 0,2);

$K_i u$ – the utilization coefficient of wind turbines' rated power (possible to take 0,305–0,457).

The annual operating costs include:

– maintenance costs and current repairs, 10 % of the wind turbines' costs divided by the operating time of 25 years;

– deductions to repay the interest rate for the loan, 10 % of the wind turbines' costs divided by the operating time of 25 years;

– deductions to the networks' exploitation, 6 % of the annual income of electricity sales;

– taxes, 10–15 % of the annual income of electricity sales;

– no fuel costs, wage costs are low and are included into the costs of the wind turbines' maintenance.

Table 7.4. Calculation of per unit costs of wind turbines

Cost characteristics	Costs, euro/kW
Wind generator (turbine)	1300
Foundation for wind turbines	35—40
Transportation costs	45—55
TP 0,69/20(10) [8] kW	35—50
TP 20 (10)/110(35)kW	45—55
Road construction	14—16
Cabling of the wind park of wind turbines	26—29
Transmission lines for a wind park	37—40
Mounting of wind turbines (a special crane)	35—50
Commissioning (stetup)	15—25

For the Republic of Belarus:

– a preferable variant of the wind turbines' construction is the sites located in Grodno, Vitebsk and Minsk regions, where the average annual wind's speed is at the altitude of 10 m above the ground and exceeds 4,8 m/s, and at the altitude of 100 m – more than 10 m/s;

[8] *The numbers in brackets are referred to the energy system of Belarus.*

– a reasonable choice of wind turbines with capacity of 1,5–3 MW with an estimated wind's speed of 11 m/s and a support height of 110 m;
– it's not recommended to implement wind turbines with capacity less than 1 MW, dismantled in the countries of the European Union in connection with the technical rearmament of the world wind energy;
– when designing wind turbines it's necessary to take into account their expansion possibilities, and the components' selection of an electric connection circuit with an energy system;
– at the present stage the introduction of small wind turbines is considered to be inappropriate.

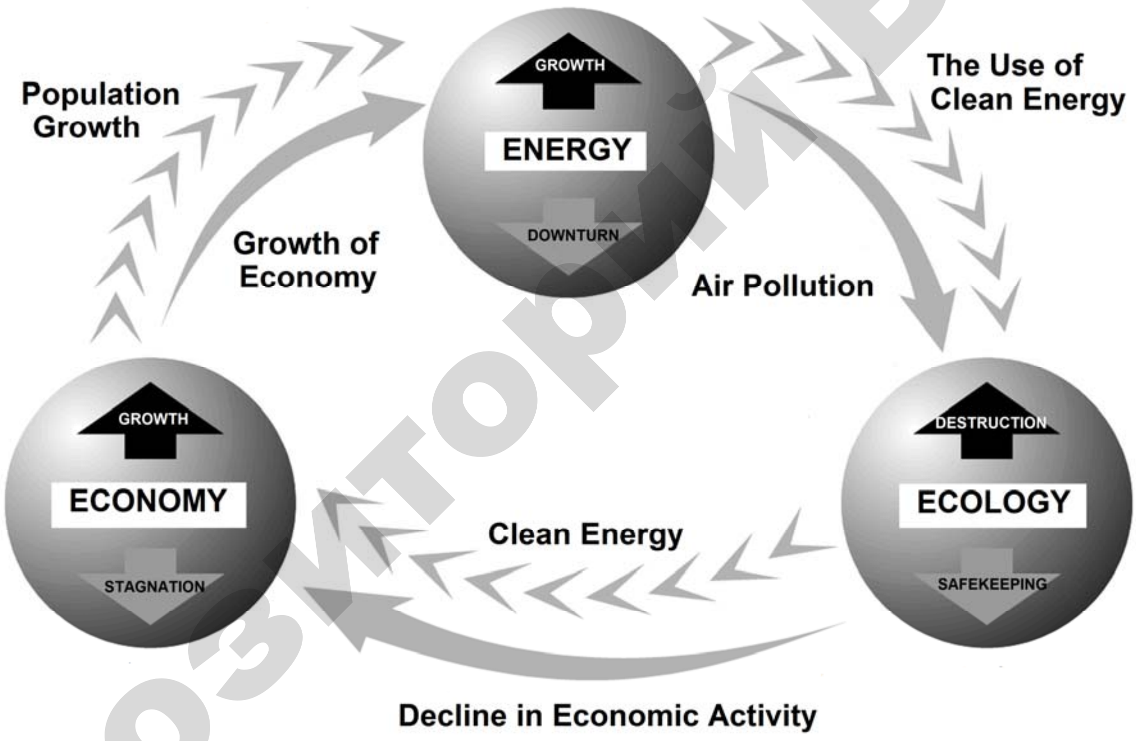


Figure 7.14. Trillema

A global strategy of the energy development, and therefore of a whole civilized life on Earth in the XXI century, is well illustrated by the so-called 3E-trilemma (Figure 7.14) – (E: Economics, E: Energy, E: Ecology) [42]. To enhance an economic development it is necessary to increase energy production and consumption under a conventional method of civilization development according to a standard way. However, it creates serious ecological problems due to the increased emission of harmful substances into the environment. And on the contrary, if a policy choice of the states aimed at reducing harmful emissions, it inhibits the economic development. The only way to resolve this trilemma is to develop environmentally friendly energy generationing technologies.

The question of a wide use of renewable energy sources in Belarus must be tackled. And it's not that our country has no significant commercial reserves of oil, gas or other fossil fuels. Global trends in the use of alternative energy sources such that they are not initially acquired by the countries deprived of natural resources, but by the countries with a developed scientific and technical base where the environmental issues are not in the last place.

Of all types of renewable energy sources the most attractive in this sense is solar energy, in particular a method of its direct conversion into electric energy using photoelectric energy convectors. They are characterized by a very long service life, have no moving parts, do not create noise, their work is not related to emission of any harmful substances, and therefore the solar cells are very attractive to consumers as an alternative to conventional energy sources. They combine well with a modern building design, moreover, due to more efficiency (at least 14–15 %) and a modular principle of a capacity building, they be can used in the systems with capacity of up to several MW – "solar power stations" that can be the components of the regional energy systems.

The perspective of the photoelectric convertors' usage, as a renewable energy source, has been proved by an increase in production of solar batteries worldwide, over the past 2–3 decades, approximately 25 % per year.

In addition, solar energy has low spatial density. For a solar energy transformation into electric, sufficiently large sites must be used. For Belarus, the annual electricity consumption in 2013 was 30,5 billion KWh [40]. To cover this need it's necessary about 230 km^2, or 0,11 % of the territory of the republic. It means that the square of 15,2×15,2 km^2, used for a solar power station can satisfy all needs of our country in electricity. Belarus is a state with a relatively low population density; in addition, there is a significant area of the Chernobyl zone, temporarily unfit for agriculture or humans' habitation. This area is suitable for the sites where solar power stations can be constructed.

8. Waste reclamation in the systems of the agroindustrial complex

The territory of the Republic of Belarus is 207,6 thous. sq. km. The length from north to south is 560 km, from east to west is 650 km.

The agricultural lands cover 44,9 %, among them arable lands that cover 30 % of the total area. The underutilized lands in the national economy (sands, bushes, marshes, etc.) make up 15 % of the total area. The population of the Republic of Belarus is 9463 thous. people, according to 01.02.2012. 1885,1 thous. people live in Minsk. More than 75 % of the population lives in urban areas and only 25 % lives in rural areas. The population dynamics since 1990 is shown in Figure 8.1.

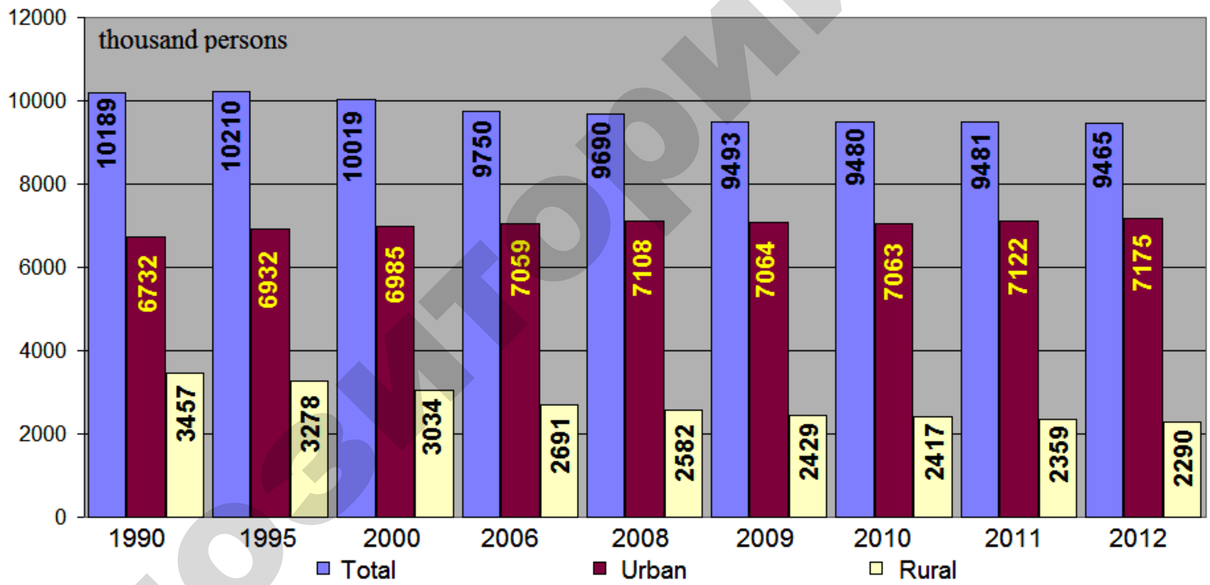


Figure 8.1. Urban and rural population size of Belarus

The agriculture of Belarus specializes in cultivating traditional crops for temperate latitudes. The crop production is mainly dominated by such grains as barley, rye, wheat, potatoes, and fodder crops. With regard to structural reforms and an orientation towards renewable energy resources, the cultivation of cereals and oilseed crops is expanding in the republic.

Animal husbandry is mainly dominated by the growth of cattle for milk and meat production, as well as pigs and poultry. The dynamics of livestock and poultry since 2004 is shown in Table 8.1

Table 8.1. Livestock and poultry at the beginning of each year

Years	Cattle	Pigs	Sheep	Houses	Poultry
2010	4151	3782	127	125	34,1
2011	4151	3887	124	113	37,0
2012	4247	3989	125	100	40,0

The power system of the Republic of Belarus is complicated, but perfectly integrated into the overall single power network of neighboring states (the diagram of the power system of Belarus and neighboring countries is presented in Figure 8.2).

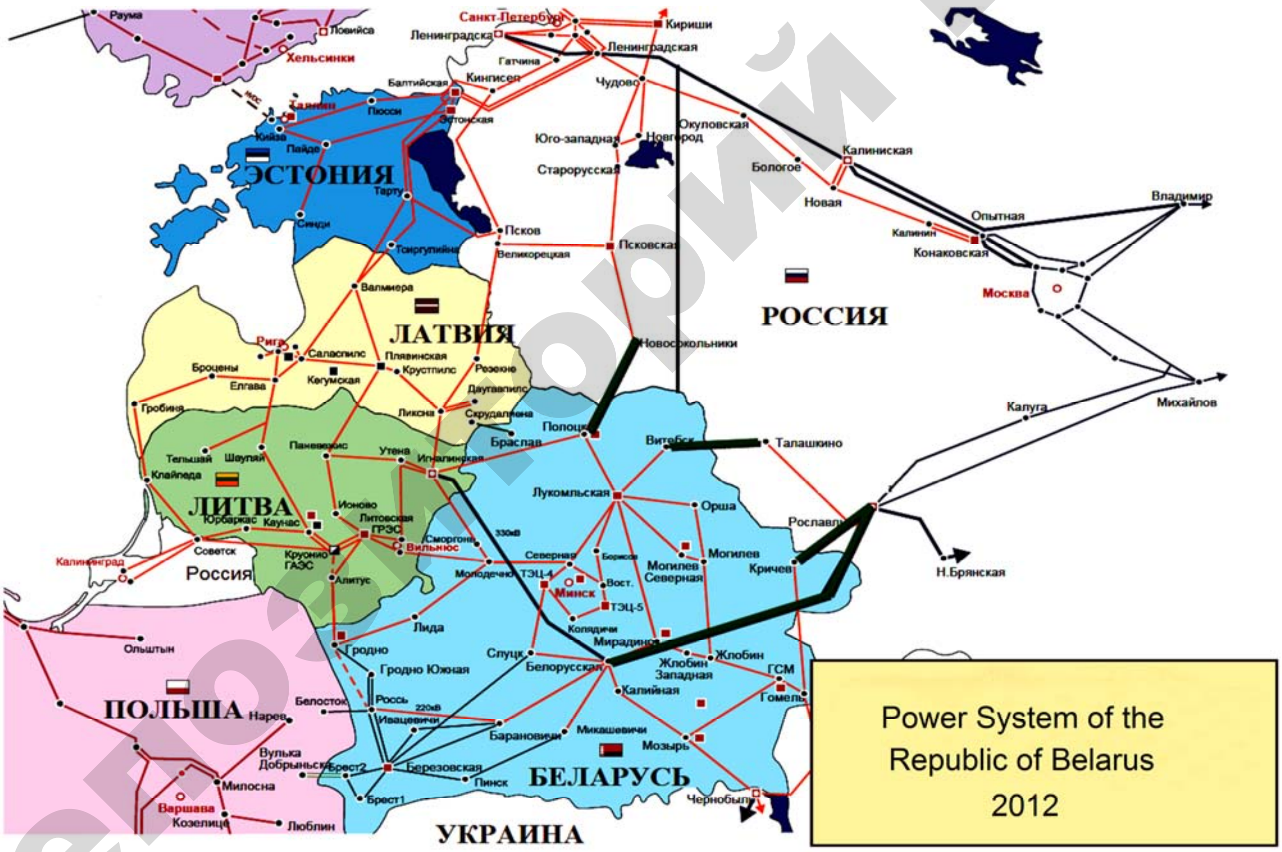


Figure 8.2. The diagram of the power system of the Republic of Belarus

Among the energy companies of Belarus, Russia, Estonia, Latvia and Lithuania, the electrical networks of which operate in a single electric ring; a special Agreement on the parallel operation of the power systems has been signed from February 7, 2001.

Bioenergy – technologies of the use of renewable organic resources, of the so-called biomass for energy production including electricity, energy of liquid, solid and gaseous types of fuels, heat, chemicals and other materials. Bioenergy is the most powerful source of renewable energy after the sun.

Fuel from biomass is beginning to become more popular due to the increasing prices for fossil fuels. Furthermore, the use of bioenergy resources reduces pollution, helps control carbon dioxide emissions.

What is biomass? How is it used to produce heat and electricity?

Biomass is any materials of a biological origin, by-products and various organic wastes. Biomass will continue its existence on Earth, yet there is life on it. According to the UN Economic Commission for Europe the annual growth of organic substances on Earth is equivalent to the production of such an energy amount that is in ten times more than the annual energy consumption by all humankind at the present stage.

The main directions of the biomass usage in the energy sector:

the first group

– firewoods (coniferous, broadleaved species and fast-growing trees);

– pellets' production (wood pellets or peat-like);

– fuel bricks' production (wood, grass, peat);

– wood chips' production (for direct combustion);

– straw or grass bales (in special furnaces);

the second group

– gasification;

– pyrolysis;

the third group

– ethanol production;

– biodiesel production;

the fourth group

– biohydrogen production;

the fifth group

– biogas production.

In Belarus, the development of bioenergy is economically viable and technically feasible. In Belarus there are more than 6,300 cattle-keeping complexes; more than 100 pig complexes and 60 poultry complexes on the basis of which annually millions of tons of wastes are produced (Table 8.2).

Table 8.2. Output forecast of manure and litter in 2012, t

Animals (poultry)	Cattle	Pigs	Poultry
Manure output (litter)	212 350	79 780	2 400

These wastes (practically without their pretreatment) are dumped on the fields as fertilizers. However, in addition to their benefits, they simultaneously do a significant environmental harm. Wash-outing with the snow and storm waters, manure from the fields, and also not neutralized waters of livestock enterprises, especially of pig complexes, fall into pounds. Such sewage waters contain a large amount of nutrients including phosphorus and nitrogen that contribute to the mass algae development.

The biogas potential from all the sources is 160 thous. tons of oil equivalent in a year.

The sources of biomass that are typical of our country can be divided into five main groups:

– natural vegetation products (wood, wood wastes, wood garbage and peat);

– biomass of plant's origin (canola, straw, bagasse, silage, etc.);

– human wastes (solid household wastes, industrial wastes and precipitations of treatment plants);

– agricultural wastes (manure, chicken manure, tops, etc.);

– wastes of the agroindustrial complex (molasses, ethanolic barda, mash potato, technical glycerine, wastes of meat and milk processing, etc.);

– specially cultivated and fast-growing agricultural crops, plants and forest plantations.

In the Republic of Belarus, solid household wastes are sent to dumps and two recycling plants (Minsk and Mogilev). The following things are annually disposed of (thousands of tons): paper – 648,6; food wastes – 548,6; glass – 117,9; metal – 82,5; textiles – 70,8; wood – 54,2; leather and rubber – 47,2; plastics –70,8. The content of organic substances in household wastes is 40–75 %, of carbon is 35–40 %, the ash content is 40–70 %, the combustible components in household wastes make up 50–88 %, the calorific value of MSW is 800–2000 kcal/kg. The potential energy contained in solid household wastes, generated on the territory of Belarus, is equivalent to 470 thous. of tons of oil equivalent.

With their processing in order to obtain gas, the efficiency is not more than 20–25 %, which is equivalent to 100–120 thous. of tons of oil equivalent. In addition, it is necessary to take into account long-term reserves of the MSW, which are available in all major cities and create problems of their storage. Only in regional cities the annual processing of municipal wastes into gas would make it possible to get about 50 thous. of tons of oil equivalent and in Minsk – up to 30 thous. of tons of oil equivalent of energy. In general, in Belarus only 16 % of wastes can be processed.

The effectiveness of this direction should be evaluated not only by the biogas output, but also according to the environmental component, which is the main in this issue.

To obtain useful products or substances biomass requires processing, which has a complex character and solves a number of extremely important issues:

– sanitary and environmental (decontamination of wastes);
– agrochemical (obtainment of effective organic fertilizers);
– energy (obtainment of high-quality fuels, and heat and electric energy);
– social (improvement of working and living conditions of the population, an increase in crop yields, improvement of animal productivity, reduction in the use of pesticides, etc.).

Currently there are the following major biogas plants in the agricultural sector: JSC “Gomelskaya poultry farm” (340 kW); RUSP SGC “Zapadnyi” (500 kW); poultry breeding plant “Belarusian” (340 kW), SPK “Agrokombinat Snov” (2 MW) and SPK “Rassvet” im K.P. Orlovskogo (4,8 MW).

Realizing the significance of such issues as energy conservation and wastes disposal in the Republic of Belarus by 2014 it has been planned to complete new large projects –7 biogas plants and complexes working on agricultural wastes, with electrical capacity of 1–3 MW. These include the following: JSC "Gastellovskoe" (electric capacity is 3 MW); JSC "State farm-factory SOG" (electric capacity is 1 MW); JSC "Lipovts" (electric capacity is 1 MW); SPK "Mayak commune" (electric capacity is 1 MW); RUSP "Pig complex Borisov" (electric capacity is 1 MW); RUSP "State farm Slutsk" (electric capacity is 1 MW) and SPK "Vishnevetskii" (electric capacity is 1 MW). With the foreign investors' assistance it is planned in the same period to build 6 biocomplexes at wastewater treatment plants and 5 biocomplexes at distilleries. These include the following: "Minskvodokanal" (investments are about \$20 million and \$15 million); "Bobruyskvodokanal" (investments are about \$5 million); "Baranovichivodokanal" (investments are about \$5 million); "Bobruyskvodokanal" (investments are about \$4 million); "Slonimvodokanal" (investments are about \$3 million) and 5 complexes of "Belgopischeprom" (investments are about \$15 million).

It should be noted that the main environmental production benefit of biogas technology is that it reduces emissions of methane, carbon dioxide and nitrogen oxides into the atmosphere. Since, during a fermentation process exactly the same amount of carbon dioxide is allocated which was previously absorbed by plants during a process of photosynthesis; and methane, having in 21 times a greater impact on the greenhouse effect than carbon dioxide, captured and not released into the environment.

The state policy implementation in the field of renewable energy sources is carried out according to the documents [8, 16–20].

The development of agriculture of the Republic of Belarus will be carried out in accordance with the State Programme to Strengthen the Agrarian Economy and Rural Development for 2011–2015. The most important tasks of the agricultural development are to form a competitive and environmentally friendly agricultural production, to meet the country's needs in full demand, to increase the export potential, and ensure an increase in return on sales.

Figure 8.3 Biogas plants of "Agrokombinat Snow"

Figure 8.4. A biogas complex for 4,8 MW in SPK "Rassvet" im K.P. Orlovskogo

The priority directions leading to the improvement of the agricultural production are the following:

– creation of highly integrated structures of a corporate type for technological food chains from the production of raw materials to the finished products' sales;

– intensification of an agricultural production through an effective use of production and climatic conditions, human resources, a marketing infrastructure in the country and abroad with a focus on the needs of the processing industry and the demand on a global food market;

– modernization of organizations' processing of agricultural raw materials, introduction of a new equipment and technologies which are suitable for a deep raw materials' processing, expansion of its range and the output with a high added value.

The environmental policy held in Belarus is aimed at ensuring an environmental safety, an efficient use of natural resources while maintaining the integrity of natural complexes, including the unique ones. The main directions of its implementation are:

– a substantial improvement of the environmental components' quality by developing a technological level of production;

– a reduction of the wastes' production volumes, emissions of the polluting substances to the atmosphere and discharges of the polluted wastewaters into surface waters, prevention of the groundwater pollution and soils, degradation of agricultural lands;

– implementation of a set of measures to prevent and minimize damage caused to the environment by technological and natural disasters by means of carrying out preventive organizational and technical measures in the sphere of production, adoption into practice of modern methods, technologies and equipment for hydrometeorological observations and preparation of hydrometeorological forecasts;
– an increase of the wastes' involvement level into civilian circulation, disposal of the accumulated hazardous wastes of production;
– conservation of biological diversity, natural landscapes, natural ecological systems by developing a network of the specially protected natural areas;
– development of a national environmental monitoring system through the introduction of advanced technologies of observation, data collection, acquisition and presentation of environmental information;
– environmental consciousness formation of the population through an educational system;
– environmental risks' prevention connected with an increase of emissions of greenhouse gases into the atmosphere, an anthropogenic climate change and man-made disasters.

The tasks related to the efficiency improvement of local and renewable energy resources in the Republic of Belarus are the following:

1. To reduce the GDP energy intensity to the level of 2005: no less than 50 % in 2015; no less than 60 % in 2020.

2. To ensure energy resource savings (in comparable conditions): no less than 7,1–8,9 mln tons of oil equivalent in 2011–2015; no less than 5,2 mln tons of oil equivalent in 2016–2020.

3. To provide the share of the own energy resources' usage in the energy balance to produce heat and electricity: no less than 25 % in 2012; no less than 28 % in 2015; no less than 32 % in 2020.

The funding activities to use the energy and domestic energy resources rationally during 2010–2015 are presented in Figure 8.4. The total funding amount is $ 8662,5 million.

The programme of the energy sources' construction running on biogas has the following objectives:

– reduction of an environmental impact on the environment;

– biogas obtaining and its usage to generate electric and heat energy in order to replace the imported energy resources;

– obtainment of high-quality organic fertilizers;

– reduction of the crop acres' contamination from using unprocessed organics.

As a result of the Programme's implementation in the country 39 biogas plants with total electricity capacity of 40,4 MW will be put into operation, which will annually produce about 340 million kWh of electric energy and replace the imported natural gas in the amount more than 145 thous. tons of oil equivalent.

The implementation of a national programme "The development of local, renewable and alternative energy sources for 2011–2015" involves:

– construction of 102 biogas plants in rural organizations and in the housing and public utility sector, microbiological industry, and at the sites of municipal and household wastes with a total electrical capacity of 77,8 MW;

– wind power stations' construction with total electrical capacity of 365–385 MW;

– introduction of 184 solar power plants for the needs of hot water supply;

– introduction of 166 heat pumps to use low potential secondary energy resources and geothermal energy.

Under the conditions of a global financial crisis and limited resources the efficiency improvement of the fuel and energy resources' usage acquires a special significance for the republic. Saving is becoming not just a mandatory management principle, but the most important requirement to maintain a national security of the country.

The key areas of scientific-research and prospecting works for the bioenergy development in Belarus are the following:

– acquisition of new information on the resources of biofuels and its characteristics;

– processes' study and establishment of the preparation technologies' foundations, processing and conversion of biofuels in energy products;

– a study of the related environmental problems, including pollution of the surrounding area with residuals and emissions of harmful gases (sulfur oxides, nitrogen, etc.).

– development and grounding of the technologies of recycling materials' usage to produce fuel, heat and electricity;

– assessment of the economic feasibility potential of bio-resources to produce fuel, heat and electricity, including their use in agricultural settelments.

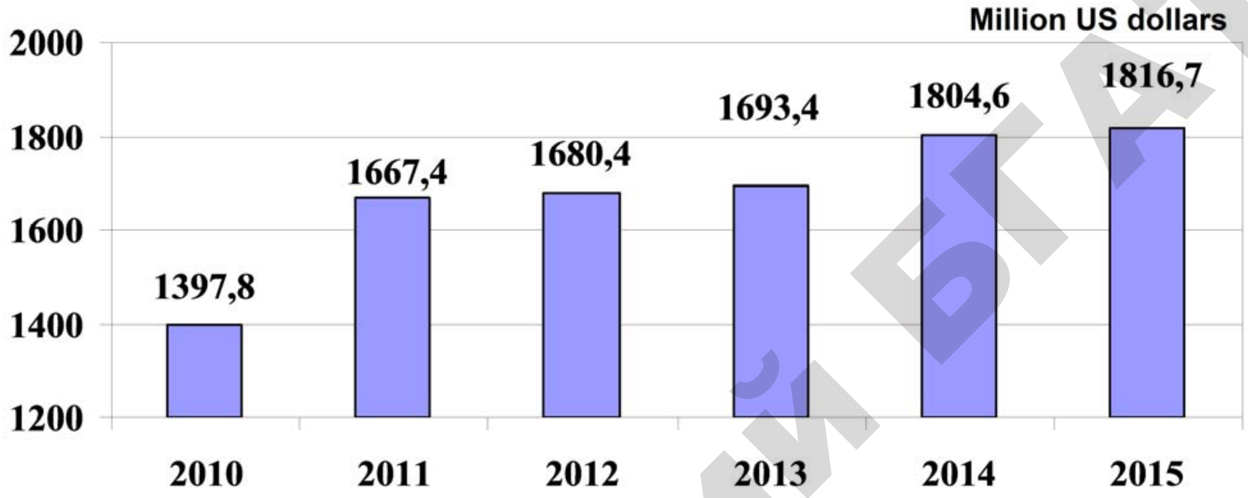


Figure 8.5. Funding amount of energy-saving activities

According to the analysis of the biogas plants' functioning, the main reasons preventing from the biogas energy development in the Republic of Belarus have been identified.

The biogas plants' construction is the only direction that allows the organizations of the Ministry of Agriculture to significantly increase the share of local fuels in the balance of boiler and furnace fuels, as well as to increase the use of alternative energy sources. Potentially possible capacity of biogas plants in the agricultural sector of the republic is as follows, according to 01.01.2013: on the farms for cattle breeding is 70,7 MW; on pig complexes is 72,8 MW; on poultry farms is 31,7 MW. In accordance with the existing potential of bio raw materials (Table 8.1) in the National programme "The development of local, renewable and non-conventional energy sources for 2011-2015" it has been planned to construct 102 biogas plants with total electrical capacity of 77,8 MW, and in the organizations of the Ministry of Agriculture it has been planned to build 22 biogas plants with total capacity of 21,7 MW.

Nowadays in Belarus there are 6 biogas plants running on manure and poultry litter, with total installed electric capacity of about 9,0 MW. In Belarus the most successful biogas project has been implemented at the agricultural enterprise RUSP SGC "Zapadnyi". The plant, operating on pig manure, built by the German company "Biogas Nord". In order to stabilize the biogas output, the fish processing wastes of the company "Santa Bremor" are being used, as well as the grain processing wastes. Electricity generation is at a constant stable level (Table 8.3).

Table 8.3. Technical characteristics of the plants' exploitation [21]

Name	Biogas plant			
	Poultry breeding plant "Belarusin"	RUSP SGC "Zapadny"	JSC "Gomelskaya poultry farm"	SPK "Rassvet" im K.P. Orlovskogo
Date of putting into operation	2008	2008	2009	2012
Capacity, kW	340	520	330	4800
Fermenter, m^3	1500	1500	1500	8×2890
Planned biogas output, m^3 per day	6720	4700	4000	48600
Actual biogas output, m^3 per day	1953	4900	-	26691
Planned electricity generation, kWh / per day	16320	10110	8025	111781
Actual electricity generation, kWh / per day	4200	10500	-	59127
Planned heat generation, Gcal / per day	17,8	1103	8540	107519
Actual heat generation, Gcal / per day	4,7	1200	-	56873

Please note: actual generation is taken for 2012; a biogas plant JSC "Gomelskaya poultry farm" didn't work in 2012.

A biogas complex SPK "Agrokombinat Snov" was put into operation in December 2011. The plant's construction was financed by the Swiss company "TDF-Ecotech Technology". The plants work on a mixture of cattle manure and pig manure. At the present stage the biogas plant has a load of 50 %, as cattle manure contains a lot of sand; the generated heat energy is not used, that leads to losses and an increase of the project's payback period. The meat processing wastes, of its own meat-processing factory, and the grain processing wastes are not used as additives in manure, but expensive maize silage is used.

The analysis of the biogas plant's current exploitation in the poultry breeding plant "Belarusian" shows that the energy production decreases from year to year indicating an ineffective use of the invested budget funds. A failure to perform the plant's set parameters is due to the extreme violations of the biogas production technology and exploitation of the plant's equipment (maintenance and scheduled preventive repairs are not performed).

A similar situation is observed at a biogas complex at JSC "Gomelskaya poultry farm".

At a biogas complex "SPK "Rassvet" im K.P. Orlovskogo" out of the four blocks (with installed capacity of 1,2 MW), only two blocks operate at nominal conditions and fully use thermal energy for technological needs of the complex and adjacent agricultural objects. The main reason is a lack of plants' raw materials (substrate).

It should be noted that according to the law [17], for the first 10 years from a moment of the biogas plant's introduction into operation, the multiplying coefficient of 1,3 is set in the sale of electric energy to the state networks, which should stimulate the bioenergy development.

However, the analysis of the biogas plants' exploitation has identified a number of constraints and technological deficiencies. Taking into account a very high cost of biogas complexes, a difficult financial situation of the Ministry of Agriculture and high interest rates on bank loans, the realization of projects' implementation of these complexes, using their own funds or bank loans, is not feasible for most organizations. The only possibility to implement the projects stipulated by the Programme is to attract foreign investors. However, their interest in these projects is currently low because of an insufficient quantity of the existing tariffs for electric energy produced from renewable energy resources, in particular, from biogas, to ensure optimal periods of the projects' payback. To reduce the payback periods of the projects of the biogas plants' introduction and increase the investors' interest from the Ministry of Agriculture it's essential to raise tariffs on electricity generated from renewable energy resources (RER) to the level of the European countries – no less than 0,20–0,28 euro/kWh depending on capacity and type of the plant and type of the used raw materials (currently the tariff is no more than 0,14 euro/kWh). The relevant proposals have been submitted into the Ministry of Economy.

According to the State Program of the Development of the Belarusian Energy System for the duration till 2016 [13] and in order to adapt the management structure of the energy system to the market conditions, a number of measures to improve the control system have been created:

– separation of energy generation by the activity types to produce, transmit, distribute and sell electricity and thermal energy;

– ensuring the costs' transparency at all stages of production, transmission, distribution and sale of electricity and thermal energy;

– market structures' formation and organization of the national wholesale market of electric energy (capacity);

– corporatization of producing and selling electric and thermal energy companies.

The ultimate goal of the management system's improvement of the energy-system is the transition to a market economy, corporatization and privatization of energy sites, creation of a republican wholesale market of electric energy (capacity), which will contribute to:

– creation of favorable conditions to attract private capital, domestic and foreign investors in the power generating industry;

– electric energy supplies' diversification as a result of a market infrastructure and mechanisms' formation to integrate into the energy market of the European Union and the states – the members of the Commonwealth of Independent States;

– implementation of the assumed obligations by the Republic of Belarus with regard to the formation of a common electricity market of the Union State, EurAsEC and the CIS.

In this context, a forward-looking management structure of the power g enerating industry of the Republic of Belarus has been developed, including an administrative organization, which will have in its composition all the necessary structures for the operation and maintenance of a wide variety of power plants (Figure 8.6). The solution to this problem is to change an attitude to the operation of the existing biogas plants and plants under construction.

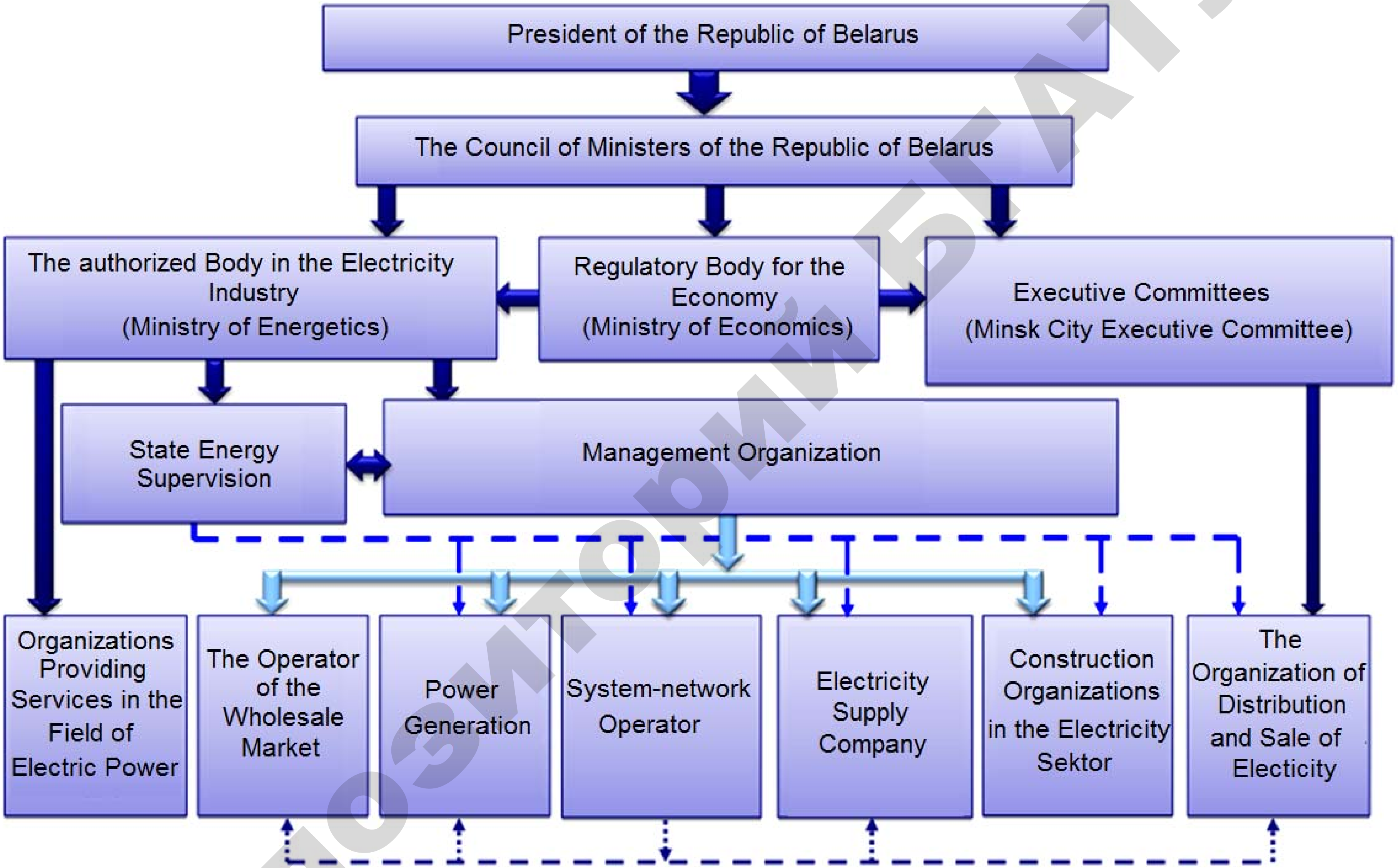


Figure 8.6. The long-term governance structure of electric power industry of Belarus

According to the analysis of the biogas plants' exploitation the following criteria for their effectiveness can be singled out:

– electric efficiency of a cogeneration plant (high pressure of a cogeneration plant is possible only under conditions of a rapid maintenance work of a biogas plant, the older the plant, the more important this aspect);

– costs and amount of technical inspections and maintenance;

– thermal energy use generated by cogeneration plants (own thermal consumption is about 30 %);

– amount of the incoming substrates (a regular measurement of viscosity and suitability for intermixing ensures an early detection of irregularities in the substrate concentration, and an operating company can pre-react to the changes of the downloadable materials) and expenditures on them (one of the main components – raw material costs that account for about 50 % of the total costs of the operating plants);

– expenditures on logistics (a very important issue, for example, at a biogas complex SPK "Rassvet" im K.P. Orlovskogo if the plant's operation is 8400 hours per year it is required to transport 34 thousands of tons of corn silage and 112 thous. of tons of cattle manure);

– costs of service and operating personnel.

According to the research results of the biogas plants it's possible to make the following conclusions reflecting the main reasons hampering the biogas energy development in the agricultural sector:

– an insufficient biotech assessment of a raw material resource base (not considering the type and amount of manure material);

– application of the uncontrolled water wash of manure drains, which leads to the presence therein of sand and foreign particles larger than 10 mm;

– a failure to comply with technical regulations on the composition (the substrate's mixture is made without taking into account the recommended values) and supply (not maintained on time and frequency) of the substrate;

– logistics of the raw materials' delivery to biogas plants is not taken into account and not analyzed;

– no stationary and mobile laboratories of the raw materials' quality control of;
– a problem of an effective use of thermal energy generated by a cogeneration unit is not solve;
– a stage construction and commissioning of biogas plants of high capacity is not envisaged;
– a lack of the trained specialized teams for maintenance and equipment repair, and other reasons.

Besides, it is urgent to create international and regional training centers in the field of the biogas plants' exploitation for specialists of the agroindustrial complex.

Thus, in the Republic of Belarus the main reclamation's direction is directed to agriculture, including the processing enterprises of the agroindustrial complex (milk processing factories, meat processing factories, ethanol plants, etc.), old dumps and sewage drains.

With regard to public utilities, both in an industrial and in private sector, it is necessary to work intensely. In the short term the organization of a separate collection of food and industrial wastes from the population is not a feasible task. Since living in high-rise buildings (8–16 floors) and having a garbage disposer, the residents are unlikely to carry out a separate waste collection voluntarily. Moreover, the availability of special services (firms) that would be involved in the delivery of the collected wastes for the intended purposes is essential, unfortunately they don't exist. Sooner or later all these problems will be resolved, on condition that there is a desire and determination to implement them. Of course, a state support is required.

Supplementary materials on the prospective use of wastes to generate energy are presented in appendix 5.

9. Distinctive features and rationing of fuel and energy resources (FER) at the sites of the agro industrial complex

The main rationing task of the FER consumption is to ensure application, while planning the output of products (works, services), technically and economically feasible and (or) progressive rates of fuel, heat and electric energy consumption.

Consumption rates of fuel, heat and electric energy resources serve to plan the consumption of all resources, evaluate the effectiveness of their use and introduce the intraproductive cost accounting at the enterprises. The rates of fuel, heat and electric energy consumption must:

– be developed at all planning levels according to the respective nomenclature of products and types of activities on a common methodological basis;

– take into account production conditions, the scientific and technological achievements and plans of organizational and technical measures involving a rational and efficient usage of fuel, heat and electric energy;

– be regularly reviewed taking into account the planned development of a technical production progress, the achieved economic indicators of FER;

– be linked with other indicators of an economic activity of the relevant planning levels (economic regulations, key figures, limits, etc.).

In production the rates of fuel, heat and electric energy consumption are classified according to the main features [12]:

a) according to the degree of aggregation:

– individual;

– group weight-average;

b) according to the cost structure:

– technological;

– shop's expenses;

– general (offsite);

c) according to time of validity:

– current (annual and quarterly);

– long-term (on an annual basis).

A TECHNOLOGICAL rate is the rate of the FER consumption, which takes into account expenditures on primary and secondary technological processes of production of a particular product, costs of maintenance of technological aggregates in hot reserves, for a warm-up and start-up after current repairs and cold downtimes. The following is not included into a technological rate of the FER consumption: unsustainable costs and losses caused by a deviation from the accepted technology; a failure to comply with the quality standards of raw materials and the defects' creation.

A SHOP rate is set per unit of products manufactured by a particular workshop. It includes: technological rates; the entire expenditure of energy resources on the supportive and the like needs of the workshop (lighting, heating, ventilation, sanitary and hygienic handling, intrashop transport, losses in the workshop's networks).

A GENERAL (OFFSITE) rate is the rate of the FER consumption, which takes into account energy consumption for primary and secondary technological processes. The secondary production needs (a general-industrial workshop and factory consumption for lighting, water supply, sewage water purification, etc..), as well as technically unavoidable losses of energy in converters, in heat and electric networks of the enterprises related to the manufacture of these products are also included in the calculation of these rates.

The following stated below is not included into the rates of fuel, heat and electric energy consumption to manufacture products:

– costs of construction and overhaul repairs of buildings and structures;
– installation, commissioning and setting up of the processing equipment (new and renovated);
– research-scientific and experimental works;
– release to a third party (for settlements, canteens, clubs, kindergartens, etc.);
– losses of fuel during storage and transport.

Fuel, heat and electric energy consumption for these needs must be normalized separately.

The main original data to determine the rates of fuel, heat and electric energy consumption are:

– primary technical and technological documentation;
– technological regulations and instructions;

– experimentally proven power balances and regulatory characteristics of energy and processing equipment;

– passport data of the equipment;

– regulatory indicators characterizing the most rational and effective conditions of production (capacity utilization coefficient, consumption standards of energy resources in production, specific heat characteristics to calculate the costs of heating and ventilation, standards of energy losses in transmission and transformation and other factors);

– data on the volumes and structure of manufacturing;

– data on the planned and actual specific costs of fuel and energy over the past years, as well as their inspection acts in production;

– data on advanced experience of domestic and foreign enterprises, producing similar products, on an economical and efficient use of fuel and energy and the achieved specific costs;

– organizational and technical measures to economize on fuel and energy.

The rates' structure of the FER consumption is a list of expenditure articles including the rates for manufacturing. The rates' structure of the fuel and energy consumption is established by relevant industrial techniques and regulations that are developed, taking into account the production peculiarities, on the basis of which at each enterprise a specific structure of the consumption rates is determined. Any arbitrary alteration in the rates' structure is not allowed.

If an enterprise manufactures in addition to the main products semi-finished goods and consumer goods for a delivery to other businesses, than the consumption of FER for production is normalized separately and is not included into the consumption rates to produce the main products.

The example of the rates' structure of the FER consumption for the agroindustrial complex (a meat-processing factory) is the presented in Table 9.1.

Table 9.1. The rates' structure of the FER consumption

№,№	Rates	Expenditure articles, included into the rate	Fuel	Heat energy	Electric energy
		Tecnological rate			
1.	Heat energy produced by industrial boiler houses	its own fuel consumption (to generate heat energy);	+	-	-
		a boiler house's needs;	-	+	+
		fuel consumption for boilers kindling;	-	+	+
		heat energy consumption for heating;	+	-	-
		fuel oil residue.			
		Workshop rate			
		tecnological rate;	+	+	+
		workshop lightning;	-	-	+
		workshop ventilation;	-	-	+
		losses in workshop networks.	+	+	+
		Consumption rates in heat and electric energy in production			
		Tecnological rate			
2.	A list of the produced items (for example, meat)	meat production;	-	+	+
		dry and cooked fodder production;	-	+	+
		auto washing, containers, inventory items, equipment.	-	+	+
		Workshop rate			
		tecnological rate;	-	+	+
		workshop lightning;	-	-	+
		workshop ventilation;	-	-	+
		losses in workshop networks;	-	+	+
		floors and walls washing;	-	+	-
		intrashop transport.	-	-	+
		Generally offsite rate			
		workshop rate;	-	+	+
		territory lightning;	-	-	+
		lightning of offsite objects;			
		heating of offsite objects;	-	-	+
		ventilation of offsite objects;	-	-	+
		losses in intraplant networks;	-	-	+
		sanitary and hygienic needs (a shower,	-	+	+
		washing and etc.).	-	+	+
		intraplant transport;	-	-	+
		maintenance of workshops;	-	-	+
		water supply;	-	-	+
		purification of sewage waters;	-	-	+
		industrial needs of repair workshops;	-	+	+
		production of the compressed air;	-	-	+
		needs of motor depot.	-	+	+

The basic methods to develop the consumption rates of fuel and energy resources are calculated-analytical, statistical reporting, calculated-statistical, and experimental methods.

A CALCULATED-ANALYTICAL method involves determining the individual rates of fuel, heat and electric energy consumption by means of the expenditure articles' calculation in accordance with the established rates' structure. In this connection it is possible to determine the rates directly "count-up" or indirectly "from the base" to change the regulatory components of energy consumption in the planning year, in comparison with the basis year.

A STATISTICAL REPORTING method involves defining the rates of the FER consumption based on a statistical data analysis on the actual specific costs of fuel, heat and electric energy, and factors influencing their alteration for a number of previous years.

A CALCULATED-STATISTICAL method involves defining the rates of the FER consumption based on a statistical data analysis on the actual specific costs of fuel, heat and electric energy, and factors influencing their alteration for a number of previous years.

AN EXPERIMENTAL method to develop the consumption rates involves determining costs per unit of fuel, heat and electric energy on the data obtained from the tests (experiments). The equipment must be in a good technical condition and well-functioning, and a technological process must be carried out under conditions stipulated by the technological regulations or instructions.

The calculated-analytical, statistical reporting and calculated-statistical methods are used to develop individual and group rates. An experimental method is used to determine only the individual rates.

Energy-saving is inextricably linked to a formation and implementation of the organizational and technical measures (OTM) to save fuel, heat and electric energy, which are developed and grouped according to the following main directions concerning the production of goods in obedience to the established nomenclature:

– processing technology improvement;
– improvement of exploitation and structure of the industrial equipment;
– improvement of the fuel and energy usage in production;
– quality improvement of raw materials and use of less intensive energy forms.

One of the most important factors of the FER efficiency is the use of secondary energy resources (SER) emerging while manufacturing some types of products and used to manufacture other products. The use of SER does not lead to a decrease in the rates of the FER consumption and to a reduction of their requirements in the manufacture, but covers a certain part of general needs.

When developing organizational and technical measures to conserve fuel, heat and electric energy, the industry-based guidelines must be used.

For example, the basic typical directions of the OTM can be defined as follows:

- introduction of energy-saving equipment, instruments, materials,
- improvement of a technology and production structure,
- improvement of the usage level of secondary energy resources, wastes production,
- improvement of the utilization coefficient of the industrial equipment,
- improvement of the efficient use of fuel and energy,
- quality improvement of raw materials and use of less intensive energy forms,
- introduction of regulation systems, control and accounting of the consumed energy resources,
- heat-generating sources' transition on local types of fuels,
- use of secondary energy resources,
- other activities (organizational, economic, and other).

A general formula to determine technological standards to manufacture any products is represented by the following expression:

$$H_T = \frac{A_{Ti}}{P_i},$$

where A_{Ti} – the annual consumption of energy resources for technological needs while manufacturing i a product's type (type of a consumed resource: W – electric energy, kWh; Q – heat energy, Mcal; B – fuel of a direct usage, tons of oil equivalent);

P_i – the annual production volume of i a product's type.

The heat energy consumption rate for technological needs while manufacturing certain products is determined in the following way.

A list of the expenditure articles is made up separately for steam and hot water for technological needs while manufacturing certain products. A list of all the installed and participating in a technological process machines and devices at the enterprise is made up in relation to the products consuming heat energy. The backup and unused equipment is not included in the calculation. A technological rate of the heat energy consumption to produce i a product's type is defined as a sum of the annual heat energy costs to perform each operation of a certain technological process.

A technological consumption rate of electric energy for a particular product is also calculated as a sum of the operational specific costs.

Further the workshop rates' calculation of the heat energy consumption is made; costs of heat energy are pre-defined according to the expenditure articles, such as:

– for sanitation of the workshop's premises (floors and walls washing);
– for shower rooms and toilets;
– for drying and washing of working clothes.

The heat energy losses in the pipelines are calculated according to the articles of the general offsite costs and further distributed proportionally to all manufactureing products. The total area of floors and panels of all the workshop's premises that are liable to be washed is determined by construction drawings.

The determination of the general workshop's rates of the heat energy consumption to manufacture products is carried out according to the formula, Mcal/t:

$$H_W = H_{Ti} + \frac{Q_{tw} \cdot H_{Ti}}{\sum (H_{Ti} \cdot P_i)},$$

where i – the index of a products' type manufactured in the workshop;

H_{Ti} – technological rates of the heat energy consumption to manufacture i a product's type, Mcal/t;

Q_{tw} – the total consumption of heat energy for the secondary needs of the unknown i workshop, Mcal.

Under the summation index there are products of a technological rate on the volume of output of i a product's type. Therefore, in the denominator of the formula, the annual output of all production of the workshop is taken into account.

To determine a general-production workshop rate of the electric energy consumption the following formula is used (Table 9.2., as an example).

The determination of the general-production rates of the heat energy consumption to manufacture products is carried out according to the formula, Mcal/t:

$$H_P = H_{Wi} + \frac{Q_{he} \cdot H_{Wi}}{\sum (H_{Wi} \cdot P_i)},$$

where H_{Wi} – a general workshop rate of the heat energy consumption to produce i a product's type, Mcal/t;

Q_{he} – the general consumption of heat energy for secondary needs of the enterprise, Mcal.

Table 9.2. The structure of the consumption rates of electric energy

Rates	Expenditure articles included in the rate (calculated formulae)	Conventional value
Technological rate (H_T)	The specific electric energy consumption according to the articles of a technological process for each unit of the electric equipment taking into account the expenditures for the equipment commissioning and losses including pack washing of the technological equipment $H_T = \sum W_i$	W_i
The general workshop rate (Hw)	1.The electric energy consumption in the technological rate structure 2.The electric energy consumption for secondary needs: electric lightning $H_w = H_{Ti} + \frac{W_{EL} \cdot H_{Ti}}{\sum (H_{Ti} \cdot P_i)}$	H_T W_{el}
The general production rate (Hp)	1.The electric energy consumption included into the structure of the general workshops rates 2. The electric energy consumption for secondary needs	H_w

Rates	Expenditure articles included in the rate (calculated formulae)	Conventional value
	of the enterprise: lightning of the territory and objects sanitary and hygienic needs water supply and purification of sewage waters industrial needs of repair workshops losses of electric energy in intraplant networks and transformers $H_p = H_W + \frac{(W_{LT} + W_{shn} + W_{WS} + W_{IN} + W_{nt}) \cdot H_{Wi}}{\sum (H_{Wi} \cdot P_i)}$	W_{lt} W_{shn} W_{ws} W_{in} W_{nt}
The consumption electric energy rate to generate 1 Gcal of heat	The electric energy consumption with the equipment of a boiler house taking part in the heat generation $H_{HB} = \frac{W_{hb}}{P_{hb}}$	W_{hb}
The consumption electric energy rate to generate 1 Gcal of cold	The electric energy consumption with the equipment to generate cold $H_C = \frac{W_C}{P_T}$	W_C

The specific electric energy consumption to manufacture products using the operational vehicles, devices and the continuous action installations with uniform load (kWh /t).

$$W_{ov} = P_n \cdot K_u \frac{A_{rm}}{q_{eq}},$$

where P_n – the nominal rating (nameplate) capacity of the electric motor of the equipment's drive, kW;

K_u – the utilization coefficient of the electric motor's capacity (can be accepted according to the Table 9.9);

q_{eq} – the equipment' productiveness on the processing raw materials or an end product, t/h;

A_{rm} – the raw material consumption, processed on the given equipment per 1 t of the finished goods, kg/t.

The electric energy consumption for the lightning of the enterprise's territory, kWh, is calculated on the formula:

$$W_l = K_d \cdot P_{ex} \cdot n_M ,$$

where K_d – a demand coefficient for the lightning installations of the exterior lighting system (can be accepted as K_d = 1,0–1,1);

P_{ex} – the total installed capacity of the lamps of the exterior lighting system, kW;

n_M – the maximum use of the lighting load (can be accepted 3500 h/year), h/year.

The calculation of the electric energy consumption of the exterior lighting production is made according to the formula:

$$W_{elp} = P_{el} \cdot T_l \cdot K_s \cdot K_d \cdot K_{st} \cdot K_H ,$$

where P_{el} – the total installed capacity of the lamps of the exterior lighting system, kW;

T_l – the lamps' operation time for a calculated period can be accepted according to the given recommendations in Table 9.3, 9.4), h/year;

K_s – the coefficient of a simultaneous switching of the lighting devices (can be accepted according to the given recommendations in Table 9.5);

K_d – the demand coefficient (can be accepted according to the given recommendations in tabl.2.5);

K_{st} – the storage lightning coefficient considering the losses of the lightning network (can be accepted according to the given recommendations in Table 9.7);

K_H – the coefficient considering the extra number of the working hours of the lamps in cloudy weather (possible to accept 1,02–1,05).

Table 9.3. Llighting load maximum while lighting the general industrial sites (recommended values)

№, №	Name of consumers	n_M, h/year
1	Administrative premises (buildings)	1150
2	Warehouses	2100
3	Washery	2100
4	Plumber's workshops	2100
5	Garages	600
6	Laundry	600
7	Charger room	2100
8	Carpenter's workshop	600

Table 9.4. The lightning installation's operating period, depending on shift-working arrangements and rated illuminance (E_H)

E_H, lux	The installation's operating period per year (*h*) at the premise's height, m							
	1,5	2,0	2,5	3,0	3,5	4,0	5,0	7,0
Single-shift work								
150	820	640	530	470	420	390	340	300
200	1110	850	700	600	540	490	420	350
300	1740	1300	1050	890	770	690	580	470
400	2150	1740	1390	1180	1010	900	750	580
500	2150	2150	1740	1450	1250	1100	910	700
Double-shift work								
150	2820	2470	2270	2130	2020	1950	1830	1690
200	3130	2750	2500	2340	2210	2110	1970	1810
300	3810	3290	2970	2740	2570	2440	2260	2030
400	4300	3840	3430	3150	2940	2780	2540	2260
500	4300	4300	3900	3560	3310	3110	2830	2490
Three-shift work								
150	4890	4520	4290	4120	4000	3900	3760	3590
200	5200	4790	4520	4330	4190	4080	3910	3710
300	5840	5320	4980	4740	4560	4420	4210	3950
400	6480	5850	5440	5250	4930	4760	4510	4200
500	6500	6380	5900	5560	5310	5110	4780	4440

Table 9.5. The value of the simultaneity coefficient

Type of premises	K_s
Premises for visitors	0,9
Industrial	0,8
Warehouse	0,7
Administration and accommodation	0,95
Commercial	0,9

Table 9.6. The demand coefficient of the lightning load

Name of the object	K_d
Small industrial buildings	1,0
Industrial buildings consisting of separate big bays	0,95
Administrative buildings and enterprises of public catering	0,9
Industrial buildings consisting of several separate rooms	0,85
Laboratories and office-everyday buildings, medical, children and educational establishments	0,8
Warehouse buildings, ancillary accommodations and etc.	0,6
Exterior and emergency lighting	1,0

Table 9.7. The storage lightning coefficient

Premises	The examples of the premises	The storage coefficient, K_{st}				
		With exterior lightning in the light-transmission material			With artificial lightning	
		vertically	transversally	horizontally	gas-discharge lamps	incandescent lamps
Premises of administrative buildings	Rooms, working and study buildings, laboratories	1,2	1,4	1,5	1,5	1,3
Industrial premises	Warehouse, workshops to keep animals	1,3	1,5	1,5	1,5	1,3

Please note: the calculated coefficient of the lighting storage considers its reduction in an operating process as a result of contamination and ageing of translucent fillings in window openings, sources of light and lamps, and also reduction of reflecting qualities of the premises' surfaces.

The electric energy consumption with a lighting system in different premises of the agroindustrial complex (The ministry of Agriculture and Food of the Republic of Belarus) should be calculated taking into account the specificity and an operating regime of lighting devices, geographical latitude of premises' location and seasonal work.

The electric energy consumption for the sanitary and household needs (produced for each user separately), kW·h

$$W_{SHN} = K_u \cdot P_n \cdot n_s \cdot n ,$$

where n_S – the number of hours per shift h.;

n – the number of working shifts per year.

The electric energy consumption for water supply, kW·h

$$W_{WS} = \sum (K_u P_{ICi} N_D N_Y) ,$$

where N_D – the number of hours per day, h;

N_Y – the number of operational days per year (usually taken N_{year} = 365);

P_{ICi} – the installed capacity i of the user, kW.

The electric energy consumption for industrial needs of repair and mechanical services (machine tools), kW·h

$$W_{RM} = \sum (K_U P_{ICi} N_Г K_M t_s),$$

where K_M – the utilization coefficient of the shift's time (can be accepted according to Table 9.8.);

t_s – the shift's length, h.

Table 9.8. Recommended values of the demand coefficient and the shift's time usage for the machine-tool equipment of repair and mechanical workshops

№, №	Machine-tool equipment	K_u	K_M
1.	A tool grinding machine with a fan	0,15	0,11–0,12
2.	A tool grinding machine	0,16	0,10–0,12
3.	A drilling machine	0,15	0,10–0,15
4.	Scissors	0,15	0,11
5.	A screw-cutting lathe	0,17–0,18	0,24–0,25
6.	A milling machine	0,17–0,42	0,16–0,27
7.	A planing-machine	0,16	0,21
8.	A grinding machine	0,16	0,14–0,15
9.	A hydraulic press	0,47	0,05
10.	A turning machine	0,18	0,11
11.	A buzz saw	0,49	0,32
12.	A jointing machine	0,37	0,16
13.	A planing machine	0,40	0,17
14.	A bandsaw	0,42	0,20
15.	Compressor	0,65	0,10
16.	A distillatory kettle	0,65	0,30

Table 9.9. The utilization coefficient of the installed capacity (Ku) of the electric equipment

Name of the equipment	K_u
Equipment for boiling and liquids' heating up	0,5
Food-cooking boilers and autoclaves	0,7
Electric cookers	0,6
Electric hot food warmer, coffee grinders	0,8
Machines for peeling and cutting vegetables	0,8
Machines for meat chopping	0,7

Name of the equipment	K_u
Machines for cutting meat and delicatessen products	0,7
Kneading machine	0,9
Automatic machine for soda water (workshop)	0,4–0,45
Cash registering machines	0,25–0,4
Drying-tiding mangles	0,8
Electromechanical presser for drying clothes	0,9
Dish washing machines (industrial hoovers)	0,8
Transporter	0,2–0,25
Cooling equipment	0,6
Lifting equipment (lift)	0,7
Lifting equipment (electric pulley block)	0,25
Packaging machines	0,3–0,4
Washing machines	0,7
Electronic scales	0,35–0,4
Teleinstallation	0,8
Hand-drier	0,2
Ventilating installations	0,6–0,8
Air-conditioning	0,7
Pressure amplifier	0,5
Compressor	0,8
Automatic telephone station	0,2
Equipment for administrative connection	0,3
Laboratory equipment	0,3–0,45
Computer equipment	0,4

The electric energy consumption with the electro-consuming equipment (in general), kW·h

$$W_{EC} = \sum (K_U P_{ICi} N_{se} T),$$

where N_{se} – the quantity of the similar equipment pcs .;

T – the number of the equipment's operating time for a calculated period, h;

P_{ICi} – the installed capacity of i-consumer, kW.

The heat energy consumption to heat buildings includes the costs of heating, ventilation, heating curtains, Gcal:

$$Q_{het} = Q_h + Q_v + Q_{hc},$$

where Q_h – the annual consumption of heat energy to heat buildings;

Q_v – the annual consumption of heat energy for ventilation;

Q_{hc} – the annual consumption of heat energy for heating curtains.

The annual consumption of heat energy to heat buildings is determined as:

$$Q_h = q_h V 24 \cdot T(t_{IT} - t_{TOA})10^{-6},$$

where q_h – a specific heating characteristic of the building, kcal /(m^3 h °C);

V – the buildings' volume on the outside measurements m^3;

T – the number of days in a heating period is defined according to [39] days.;

t_{IT} – the internal building's temperature, °C;

t_{TOA} – the average temperature of the outside air for a heating period, °C [39];

The annual heat energy consumption for buildings' ventilation is determined by:

$$Q_v = q_v V 24 \cdot (T - T_{wek})(t_{it} - t_{TOA}) \cdot n \cdot 10^{-6},$$

where q_v – a specific heat ventilation characteristic, kcal /(m^3 h °C);

T_{wek} – the amount of weekends and holidays, accounting for a heating season;

n – the average number of operating hours of the ventilation system during a day.

The annual heat energy consumption for air-heating curtains:

$$Q_{ac} = L \cdot c \cdot (t_l - t_e) \cdot n_c \cdot T_c \cdot 10^{-6},$$

where L – the amount of air delivered with a heat curtain, m^3/h (passport data);

c – heat capacity of air, equal to 0,31 kcal /m^3 °C;

t_l – the temperature of the leaving air from a heat curtain, °C (t_l = 36 °C);

t_e – the average temperature of the air entering a heat curtain, °C;

n_c – the average number of the operating hours of the ventilation system during the day;

T_c – the number of days a heat curtain operates.

The heat energy consumption for hot water supply per year, Gcal:

$$Q_{HW} = N_{HW} \cdot c \cdot m_s \cdot (t_{HW} - t_{CW}) \cdot T_w \cdot 10^{-6},$$

where N_{HW} – the consumption rate of hot water for 1 user in a day;

m – the calculated number of users;

t_{HW}, t_{CW} – the temperature of hot and cold water respectively, °C;

T_w – the number of working days per year (according to the balance of working time).

The heat consumption of other needs of hot water supply per year, Gcal:

$$Q_{on} = H \cdot c \cdot m_s \cdot n \cdot (t_{HW} - t_{CW}) \cdot T_w \cdot 10^{-6},$$

where H – the typical consumption of hot water with one water-folding tool l/ h;

m_s – the number of the same heating devices;

n – the device's operating time per day, h (the length is defined with an ordinary method).

The annual heat energy consumption for heating and ventilation of livestock buildings, Gcal:

$$Q_{HVL} = q_{HV} V 24 \cdot T(t_{IT} - t_{TOA})10^{-6},$$

where q_{HV} – a specific thermal heating and ventilation characteristic of livestock buildings kcal/(m^3 h °C);

V – the volume of buildings is determined depending on the number of animal heads, m^3.

Table 9.10. Specific heat characteristics of buildings [43]

Type of buildings	Buildings' value on the exterior measurement, thou. m^3	Specific heat characteristics, kkal/m^3 h °C	
		for heating, q_h	for ventilation, q_v
Amenity and administrative-utility buildings	0,5–1,0 1,0–2,0	0,6–0,45 0,45–0,4	– –
Administrative buildings	up to 5 up to 10 up to 15 over 15	0,43 0,38 0,35 0,32	0,086 0,08 0,07 0,06

Type of buildings	Buildings' value on the exterior measurement, thou. m^3	Specific heat characteristics, kkal/m^3 h °C	
		for heating, q_h	for ventilation, q_v
Bath houses	up to 5	0,28	1,0
Launderies	up to 5	0,38	0,8
Repair workshops	from 5 up to 10	0,6–0,51	0,2–0,15
Garages	up to 2 up to 3 up to 5 over 5	0,81 0,70 0,64 0,58	– – 0,70 0,65
Workshops of factory apprenticeship schools	5–10 10–15	0,5 0,4	0,5 0,3
Pumps	up to 0,5 0,5–1,0	1,05 1,00	– –
Through passage	up to 0,5 0,5–2	1,3–1,2 1,2–0,7	– –

Table 9.11. Calculated internal air temperature in the heated building [43]

Buildings	Premises	Calculated air temperature T_{it}, °C
Adninistrative and industrial buildings	Management, public organizations	18
Adninistrative and industrial buildings	Lobbies, wardrobes of the street clothes, tobaccos, toilets and wash basins in them	16
Adninistrative and industrial buildings	Showers	25
Adninistrative and industrial buildings	Wardrobes with the showers	23
Industrial premises	Category of work: light physical work Ia light physical work Ib moderately severe physical work IIa moderately severe physical work IIb heavy physical work III	 22 21 18 17 16
Car service	For car maintenance	5
Car service	For posts of technical service	10
Car service	Warehouses	10
Livestock buildings of cattle keeping	Cows, young cattle older than a year, bulls for service in the stalls	10
Livestock buildings of cattle keeping	Young cattle at the age of 6–12 months in boxes, group cages	12
Livestock buildings of cattle keeping	Cows and young cattle of milk species at a deep bedding	3
Livestock buildings of cattle keeping	Calves till 6 months	15

Buildings	Premises	Calculated air temperature T_{it}, °C
Livestock buildings of cattle keeping	For sanitation, a milking room	18
Livestock buildings of cattle keeping	Pig-feeding house	18
Livestock buildings of cattle keeping	Pig-house for young cattle pigs-weanling	20
Livestock buildings of cattle keeping	For sanitation of breeding pigs	25
Livestock buildings of cattle keeping	Mature bird: hens	16–18
Livestock buildings of cattle keeping	Young bird: broiler chickens, age is 1week	28-26
Livestock buildings of cattle keeping	Young bird: broiler chickens, age is 2-3 weeks	22
Livestock buildings of cattle keeping	Young bird: broiler chickens, age is 4-6 weeks	20
Livestock buildings of cattle keeping	Young bird: broiler chickens, age is 7-9 weeks	18

Table 9.12. Consumption rates of hot water by consumers [38, 43]

Name of consumer	Unit of measurement	The consumption norms of hot water N_{hw}, l/days	The consumption of hot water with a device, l/h
Laundries: - mechanical - non-mechanical	1 kg of dry clothing	15 25	in a process 200
Administrative buildings	1 in operation	7	60
Workshops with excessive heat (more 20 kkal /(m^3h))	1 operating in a shift	24	40
Other workshops	the same	11	40
Shower rooms in industrial premises	1 shower. net	270	270
Livestock farms	1 cow 1 calve 1 breeding pig 1 pig	15 2 4,5 1,5	in a process

Table 9.13. The livestock buildings' characteristics [43]

Name of a building	The number of heads (places for animals)	The volume for 1 head (places for animals), m^3	Specific heat characteristics
Cowhouses	100, 200 100, 200, 400	30–35 39–43,4	1,1–1,2 0,44–07

Name of a building	The number of heads (places for animals)	The volume for 1 head (places for animals), m^3	Specific heat characteristics
Maternity barn on farms for cattle keeping	48, 72, 90, 120	60–107	0,43–0,77
Building for nursery and feeding of cattle	250–554 720–860	19–33 13–18	0,6–0,72 1,06–1,54
Calf houses	230–784	11–16,5	0,48–0,95
Pig feeding houses	500–3750 100–760	5,4–8,7 12–29	0,75–1,2 0,68–0,93
Pig houses for single and pregnant sows	280–1200 185–300	14–19 20–29	0,92–1,4 0,64–1,05
Sow houses	60–480	27–107	0,51–0,81
Pig houses for young cattle and nursery pigs	500–3750	5–8,7	0,63–1,15
Poultry house for grown-up hens	2500–30000 480–12000	0,3–1,4 1,7–3,8	0,72–1,1 0,63–0,86
Poultry houses for young hens and broiler chickens	4500–102000	0,16–1,26	0,82–1,46

The consumption rates of heat energy for the buildings' heating and ventilation is the flow rate of heat energy per unit of the buildings' heating work and it is measured in Mcal /(thous. m^3 per day °C).

The buildings' heating work (W) is the work of the heating and ventilation systems to create comfortable conditions, performed for a certain period under certain climatic conditions. It is measured in thou. m^3 day °C.

The building's heating work i, thou. m^3 per day °C, is determined by the formula:

$$W_i = V_i (t_{iIT} - t_{TOA}) \cdot T ,$$

where V_i – the outside building volume i – of a building, m^3.

The total work of the buildings' heating at the enterprise (organization, institution) is defined as the heating amount of all heated buildings:

$$W = \sum W_i \ .$$

The annual fuel consumption B, thous. m^3, is determined taking into account the annual heating costs:

$$B = k_a Q \frac{1000}{Q_H \eta},$$

where k_a – the assurance coefficient for the neglected heating cost; it is taken equal to 1,1–1,2;

Q_H – the combustion heat of solid (gaseous) fuel Mcal /Kg (Mcal/m^3);

η – the efficiency coefficient of a generating plant.

The fuel consumption while drying agricultural production depends on humidity (Table 9.14).

Table 9.14. The consumption rates of fuel equivalent while drying grain for 1 t of dry grain [40]

Grain's initial humidity, %	18	20	24	28	32
The fuel consumption rate, kg/t	8,5	12,9	22,6	33,3	49,8

The rates of the FER consumption can be developed by business entities or special organizations can be attracted for this purpose. When planning and accounting fuel, heat and electric energy, the rates of the FER consumption must be designated in units considered in a statistical reporting: fuel (boiler and furnace fuels) in kg tons of oil equivalent.; heat energy – Mcal; electric energy – kWh; the generalized energy costs in tons of oil equivalent.

To agree on the rates of the FER consumption organizations and individual entrepreneurs must submit the following documents to the regional (Minsk city) administration for supervision of the rational use of fuel and energy resources:

– calculation of the technically based rates of the FER consumption;

– FER consumption indicators for a three-year period;

– approved rates of the FER consumption in 3 copies;

– a report on the results of fuel, heat and electric energy usage according to a form 11–FER for a previous year;

– a report on the implementation plan (programme) on energy-saving for the preceding year;

– an activity plan (programme) on energy-saving on the year under review;

– other necessary materials at the request of regional and Minsk city administration for supervision of a rational use of fuel and energy resources.

All the documents and materials must be signed by the head of the organization, individual entrepreneur and certified by the seal. The materials to agree on the rates of the FER consumption are submitted no later than 30 days before putting them into action. For consideration of the question concerning the agreed rates' correction for the current quarter (year) in accordance with an established order the required materials must be submitted no later than twenty days before the end of the quarter (year). If the total annual consumption of fuel and energy resources of the enterprise is less than 1,5 thous. tons of oil equivalent that the rates are approved by overhead organizations without the relevant departments' consent.

While agreeing the rates of the FER consumption in case of discords on the initiative of one of the parties, an independent examination must be conducted with the registration of a relevant protocol. In case of a failure to agree the rates of the FER consumption the corresponding control organizations must explain the reason for the refusal in writing to the organizations, individual entrepreneurs.

The progressive rates of the FER consumption are set for organizations and individual entrepreneurs, if their total annual consumption of fuel and energy resources is more than 1,5 thous. tons of oil equivalent.

For organizations and individual entrepreneurs not manufacturing the products (not performing any work, not providing any services related to the production of goods), progressive limits are set, which equal to the progressive consumption rates of fuel and energy resources.

The determination of the progressive consumption rates of fuel and energy resources is made with the help of a calculated-analytical method by organizations and individual entrepreneurs on their own or with the assistance of specialized organizations, as a rule after energy audit of the enterprise and development of energy-saving programme for 5 years.

Organizations and individual entrepreneurs must submit the following documents to the regional (Minsk city) administration for supervision of a rational use of fuel and energy resources to negotiate the approval of the progressive consumption rates of fuel and energy resources (the progressive limiting levels of the FER consumption).

– an energy-saving programme drawn up by the results of energy audits;

– calculation of the progressive rates of the FER consumption (the progressive limiting levels of the FER consumption);

– approved progressive rates of the FER consumption (progressive limiting levels of the FER consumption) in triplicate;

– a report on the implementation of the energy-saving programme drawn up by the results of energy audits;

– other relevant documents at the request of a corresponding regional (Minsk city) administrations for supervision of the rational use of fuel and energy resources.

All the documents must be signed by the head of the organization, individual entrepreneur and certified by the seal.

The criteria for assessing the introduction's effectiveness of the progressive rates of the FER consumption (progressive limiting levels of the FER consumption) are completeness and timeliness of the implementation of an energy-saving programme drawn up by the results of energy audits, an impact of the introduced energy-saving measures to reduce the current rates in comparison with the rates of the base year. In case of a failure to achieve the planned progressive rates of the FER (progressive limiting levels of the FER consumption) at the end of the current year, they must be corrected to a reduction side (in agreeing) by an amount that is equal to the difference of the actually reached and approved progressive rates of the FER consumption (progressive limiting levels of the FER consumption).

Head of organizations, individual entrepreneurs shall be personally responsible in a manner prescribed by law for the annual implementation of the programme on energy-saving drawn up on the results of energy audits, and for introduction of the progressive rates of the FER consumption (progressive limiting levels of the FER consumption).

An activity plan (programme) on energy-saving is drawn up according to the following main directions:

– improvement of a technology and production structure;
– introduction of the energy-saving equipment, devices, materials;
– an increase in the use of secondary energy resources, production wastes;
– an increase of the utilization coefficient of the industrial equipment;
– quality improvement of the raw materials and use of its less intense energy types;
– improvement of a more efficient use of fuel and energy;
– introduction of the systems of regulation, control and accounting of the consumed energy resources;
– heat sources' transfer on local types of fuels;
– other activities (institutional, economic, and others);
– use of secondary energy resources.

In developing an activity plan (programme) for energy-saving it is necessary to evaluate the cost-effectiveness of its implementation in order to select an optimal realization variant and implementation priority of the plan (programme).

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Appendix 1

Heat-insulating material ISOVER POLTERM 80 (hydrophobizated mineral wool plates) for weatherization of walls.

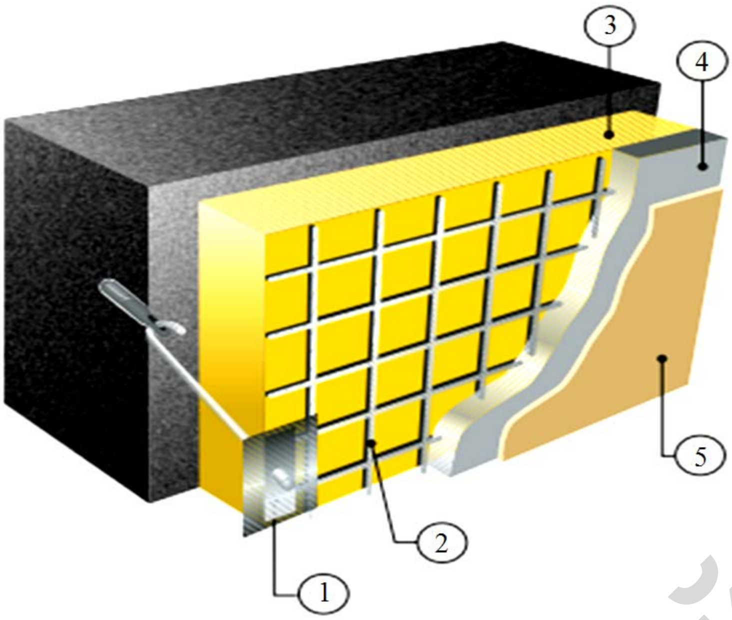

Figure П.1.1. The usage of heat-insulating plates for termorenovation:
1 – fixing mechanisms;
2 – metal mesh;
3 – heat-insulating plates;
4 – prime and squaring up solution;
5 – colored decorative compounds

Compression strength at 10 % of deformation is no less than 10 kPa.

Table A.1.1. Main technical characteristics

Name	Dimension, mm	Thickness, mm	Heat-conduction coefficient,[9] W/(m·K)
OL-E (OL-A)	600x1200	50	0,035
		70	0,036
		100	0,037
		120	0,040
		150	0,041
POLTERM 80	500x1000	50	0,040 0,042 0,045
		80	
		100	
		120	

[9] *Depends on the material's thickness; the first value is taken for standard materials.*

Appendix 2

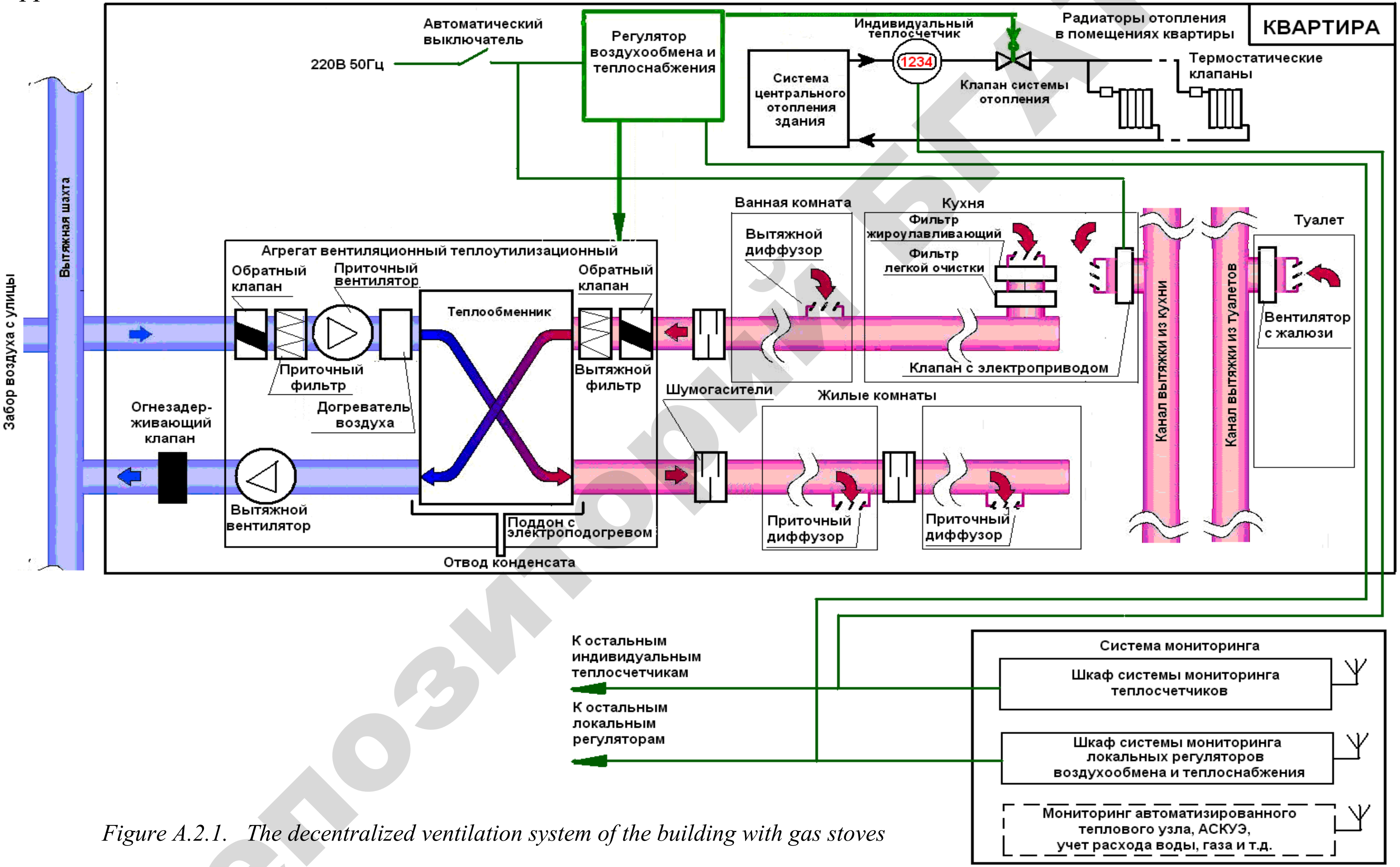

Figure A.2.1. The decentralized ventilation system of the building with gas stoves

Appendix 3

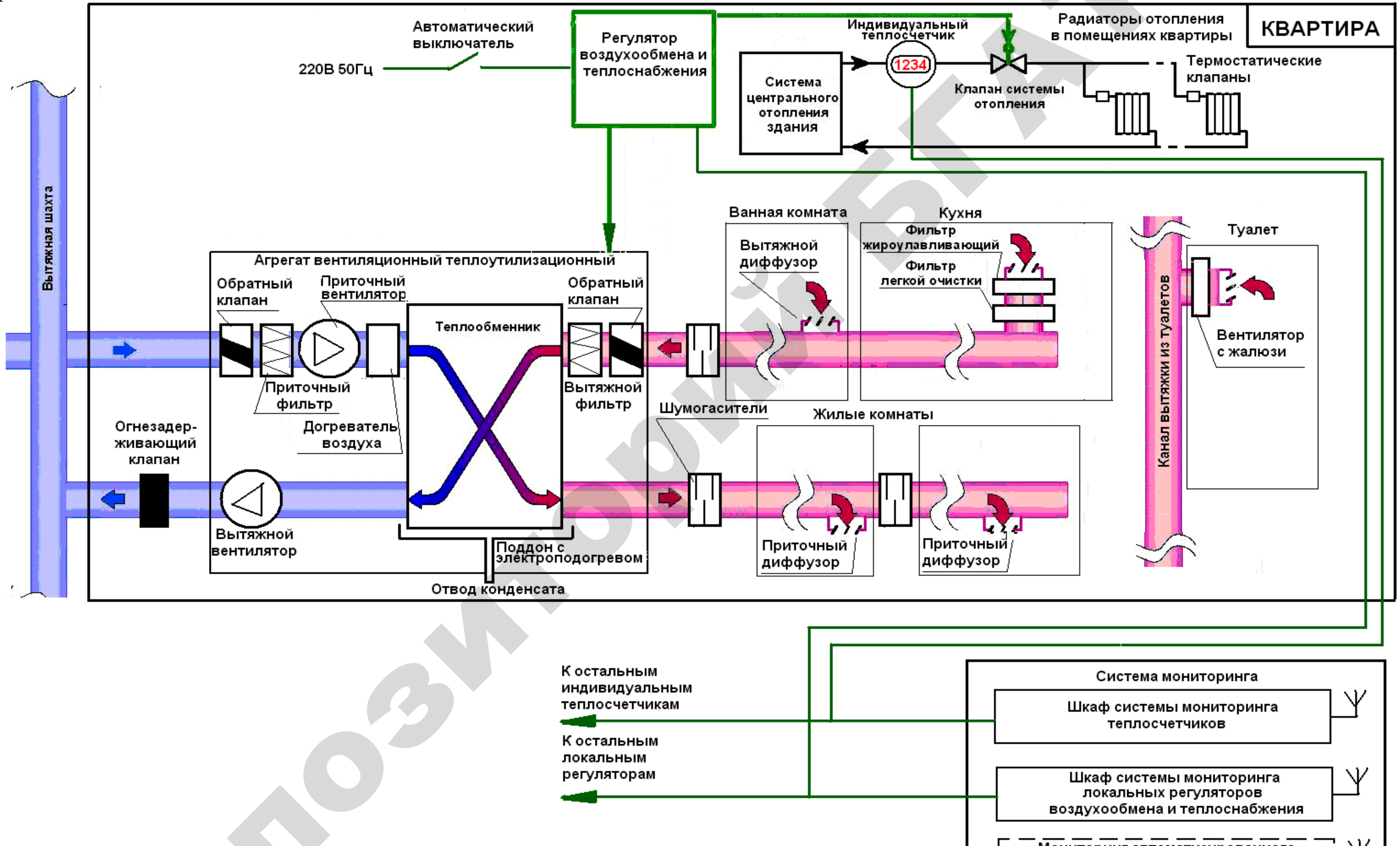

Figure A.3.1. The decentralized ventilation system of the building with electric stoves

Appendix 4

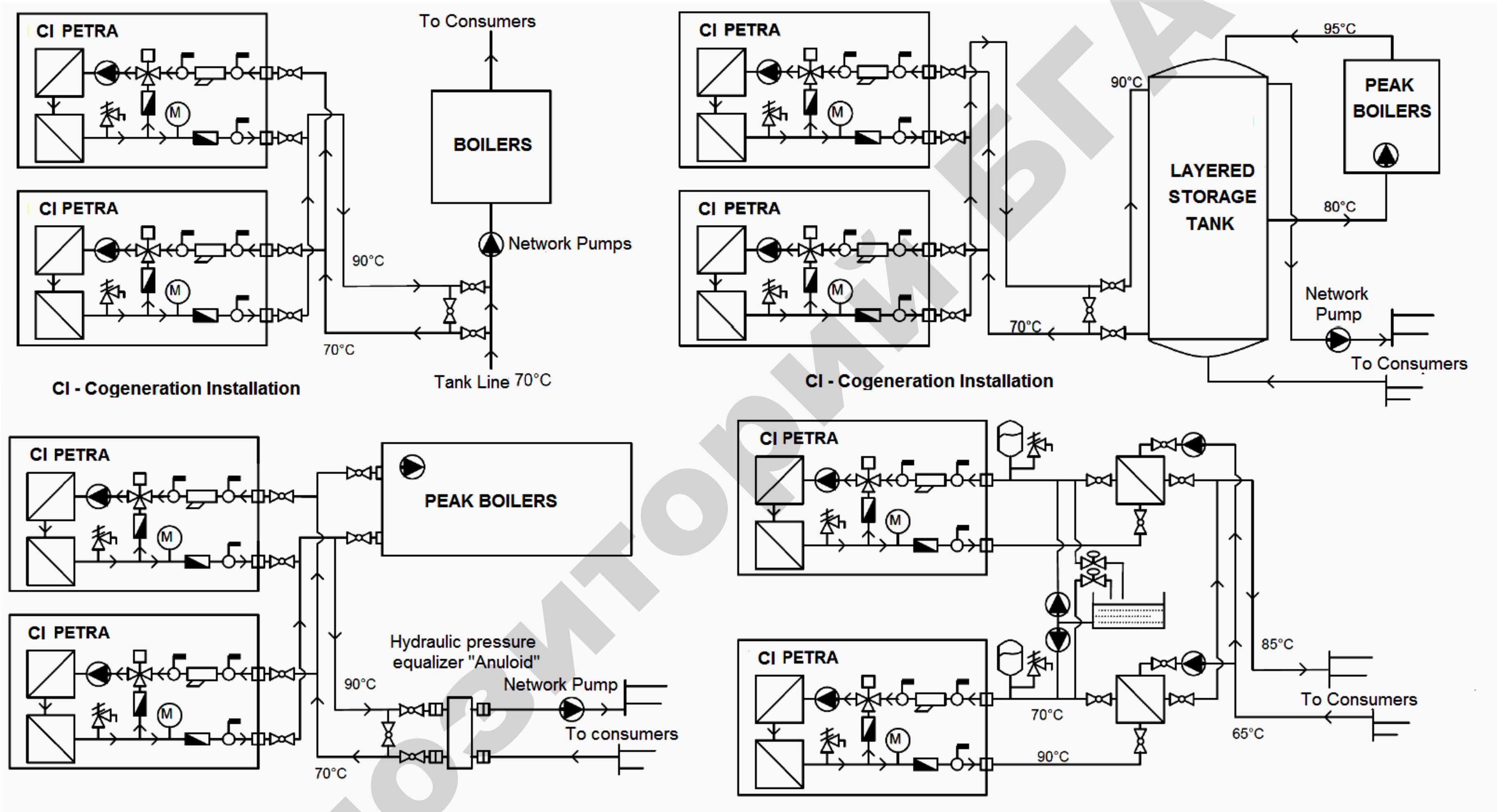

Figure A.4.1. Typical circuit diagrams connecting cogeneration units:
1 – in the boiler return; 2 – using a layered heat storage tank; 3 – cogeneration boiler using anuloida; 4 – via the heat exchangers

Appendix 5

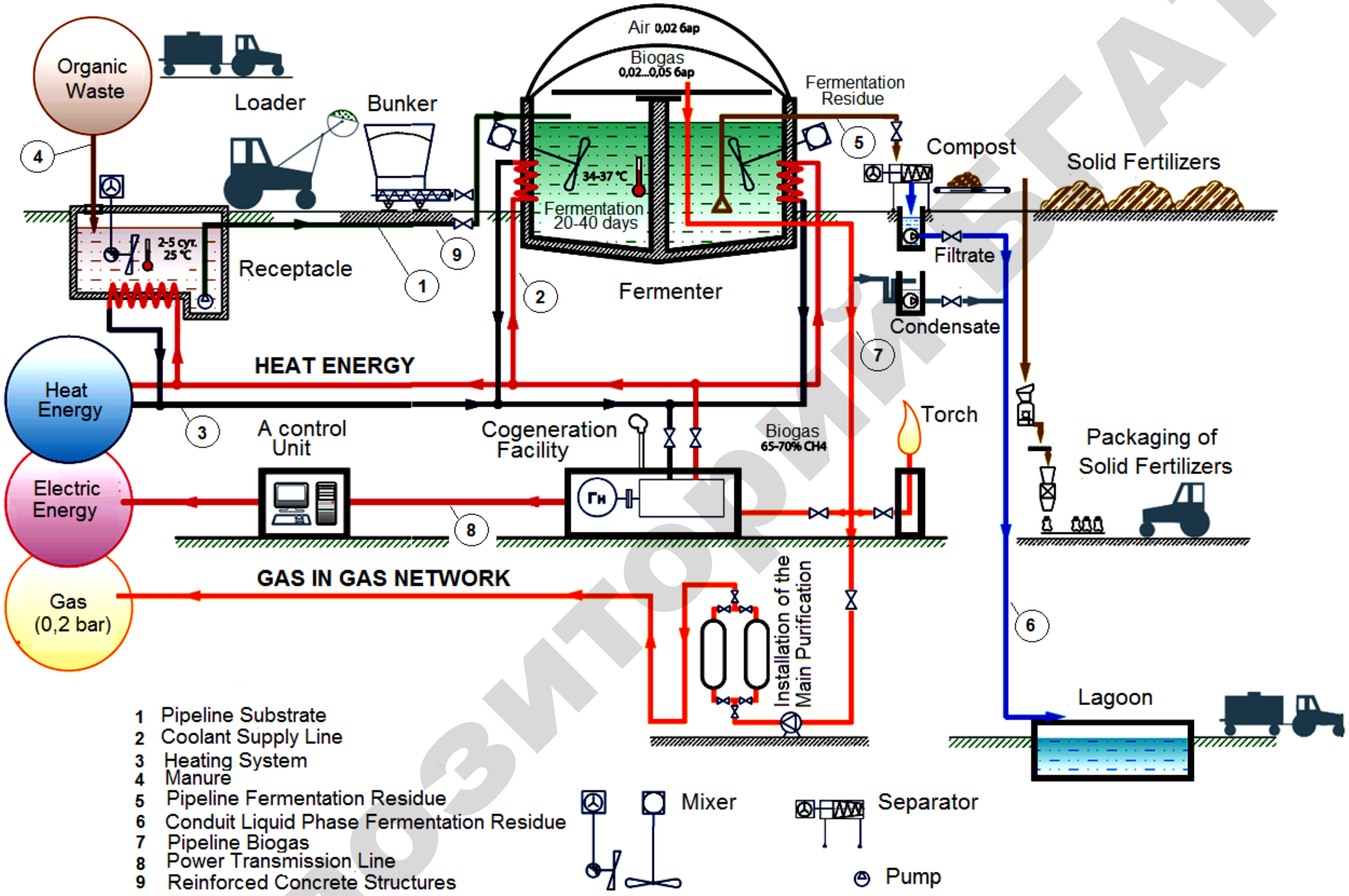

Figure A.5.1. Using cogeneration unit as part of a complex of bioenergy

Учебное издание

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