MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
KYIV NATIONAL UNIVERSITY OF
CONSTRUCTION AND ARCHITECTURE

VENTILATION EQUIPMENT FOR RESIDENTIAL AND PUBLIC BUILDINGS

Methodological Guidelines
for Practical Classes, Course Design, and Graduation Thesis
Work for Students Specializing in
G19 «Building and civil engineering»,
G17 «Architecture and town planning»,
G4 «Energy production (by specialization)»,
G2 «Environmental protection technology»,
E2 «Environmental sciences» / «Natural environments and wildlife»

Kyiv 2025

UDC 697.911
V15

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Approved at the meeting of the Department of Heat Supply and Ventilation, Protocol No. 18 of May 19, 2025.

In the Author's Edition.

V15 Ventilation Equipment for Residential and Public Buildings / compiled by: Vakulenko D., Mileikovskyi V. – Kyiv: KNUCA, 2024. – 84 p.

Includes recommendations for conducting practical classes and course design in disciplines related to engineering equipment. The guidelines cover key theoretical principles, calculation formulas, reference materials, and calculation examples for students.

Designed for full-time and part-time students in specialties of knowledge fields E2 «Environmental sciences» / «Natural environments and wildlife», G2 «Environmental protection technology», G4 «Energy production (by specialization)», G17 «Architecture and town planning», G19 «Building and civil engineering». This resource aims to support students during their studies in subjects connected to engineering systems.

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GENERAL PROVISIONS

Ventilation is intended to create and maintain normalized air parameters in rooms of buildings for various purposes. When choosing methods to maintain air parameters in a room, it is necessary to primarily consider the fulfilment of sanitary and hygienic as well as technological requirements. In addition, ventilation systems that solve ventilation tasks must meet construction, architectural, and operational requirements. A ***ventilation system*** is a set of devices for processing, transporting, supplying, and removing air.

Construction and architectural requirements include:

- Minimal equipment and installation needs (small weight and dimensions);
- Coordination of ventilation system elements with the interior of the premises;
- Industrial design and simplicity of installation;
- Possibility of phased and block construction (putting ventilation systems into operation on separate floors and in rooms served by the same systems);
- Ensuring fire safety requirements (availability of means to prevent the spread of smoke and fire through ventilation ducts and channels in the building, ventilation shafts, etc.).

The main operational requirements include:

- Convenience and simplicity in servicing during repair and reconstruction work on the systems;
- Ability to provide individual regulation of the temperature-humidity mode of air in a separate room;
- Maximum operation of ventilation systems in automatic mode (minimal intervention from service personnel);
- Centralization of the location of ventilation equipment and devices that require maintenance;
- Redundancy of ventilation system operation by controlling the operation of the main and backup fans (when one stops, the other automatically turns on with a capacity of at least 50% of the total system capacity).

Ventilation equipment is air engineering equipment installed in ventilation systems, which facilitates air exchange and air processing to maintain specified (normalized) air parameters in the serviced room [1, p. 3].

Air engineering equipment refers to technical means that ensure the movement and necessary processing of incoming air or exhausted air. Air equipment includes ventilation equipment for air conditioning, gas cleaning, and dust collecting equipment [1, p. 3].

SECTION 1.
CHOICE OF VENTILATION SYSTEM TYPE FOR BUILDINGS

The types of ventilation systems are chosen considering various factors: the purpose of the building, its volume; the nature of harmful substances released into the environment; the climatic region of the construction site, availability of secondary thermal resources; and the requirements for ventilation systems. This is governed by the relevant building codes and regulations.

The main principles of ventilation organization include the choice of air exchange type, the purpose of the system, and the method of air movement, which take into account the structural features of the building being designed.

In residential and public buildings, the following can be applied:

- General exchange ventilation, which should ensure the assimilation of heat surpluses and dilution of harmful substances to the maximum permissible concentration (MPC), as well as the removal of contaminated air to maintain normalized air parameters in the room;
- Local supply ventilation to ensure normalized air parameters in a limited space of the ventilated room or to perform a barrier function against unwanted air mass movements within it;
- Local exhaust ventilation to remove harmful substances in areas of high concentration;
- Natural ventilation, which is provided due to the difference in density of external and internal air (temperature difference), differences in air pressure, heat surpluses in rooms, and the action of wind on the enclosing structures of the building;
- Mixed ventilation (natural and mechanical).

The complexity of the adopted ventilation solution is determined by technical and economic considerations. The provision of normalized air environment parameters should be achieved using the most cost-effective and simple concepts. Based on this criterion, methods for creating and maintaining normalized parameters can be arranged in the following sequence: natural ventilation; mixed (natural and mechanical) ventilation; mechanical ventilation (with recirculation, evaporative cooling, recuperation, etc.), thus ranging from simple and inexpensive to complex and costly.

1.1 Ventilation of Residential Premises

The ventilation of residential buildings is designed to remove excess heat, moisture, and carbon dioxide emitted by people, as well as other harmful emissions resulting from cooking processes, etc. According to existing standards [2, 3], exhaust ventilation is installed in the upper zone of kitchens, sanitary units, bathrooms, and showers, and in some cases, also in living rooms.

Air supply to residential premises is provided by the transfer of air from one zone to another due to differences in temperature, pressure, and the opening of doors and windows.

In residential premises, structural elements of the building, such as ventilation shafts made of construction materials located in internal partitions, which connect to the attic of the building, are primarily used as air ducts.

1.1.1 Natural Ventilation System

In most individual residential buildings, the simplest ventilation system using natural forces–so-called natural ventilation–is employed. This type of ventilation utilizes a natural draft, whereby relatively warm air from the rooms of the house passes through ducts or channels to the roof and exits through ridge or roof devices designed for air discharge. Air intake occurs through special window vents, but in old non-sealed houses – in an unorganized manner through vents and gaps in external enclosing structures. Ventilation is designed with natural drive by the requirements [3].

Exhaust channels for natural ventilation are arranged in internal (load-bearing) walls or can be executed as appended channels in the absence of internal load-bearing walls. It is prohibited to arrange channels within external walls due to the potential condensation of water vapour that may form in the channel due to temperature differences between the outside and the inner surface, which can lead to the destruction of the external enclosing structure during freezing and thawing. When arranging an appended channel to an external wall, a gap of at least 5 cm must be provided between it and the wall. The designs of ventilation channels are illustrated in Fig. 1.1.

The minimum allowable size of ventilation channels in brick walls is 1/2×1/2 brick (140×140 mm). The distance between adjacent channels and between channels and the surface of the walls should be at least 1/2 brick (140 mm). The minimum size of appended air ducts made of blocks or slabs is 100-150 mm. In premises with normal humidity, appended channels are made from gypsum fiber or gypsum boards, while in areas with increased humidity, they are made from slag concrete or concrete slabs with a thickness of 35-40 mm. In modern large-panel buildings, ventilation channels are manufactured as special blocks or panels made of concrete, reinforced concrete, etc.

Air removal from kitchen and sanitary facilities in multi-storey buildings is carried out using assembled vertical or horizontal channels–collectors, to which exhaust channels from individual rooms connect under the ceiling (see Fig. 1.2).

Horizontal collectors are made as ceiling-mounted ducts. For buildings up to five storeys, ventilation units are made with individual channels for each floor (see Fig. 1.2, b), while for buildings over five storeys, ventilation units are made with a satellite channel that connects to the main shaft (vertical collector) through one or more floors (see Fig. 1.2, a). The use of these channels (see Fig. 1.2) allows for ensuring the fire safety of ventilation systems, sound insulation, and compliance with sanitary and hygienic requirements.

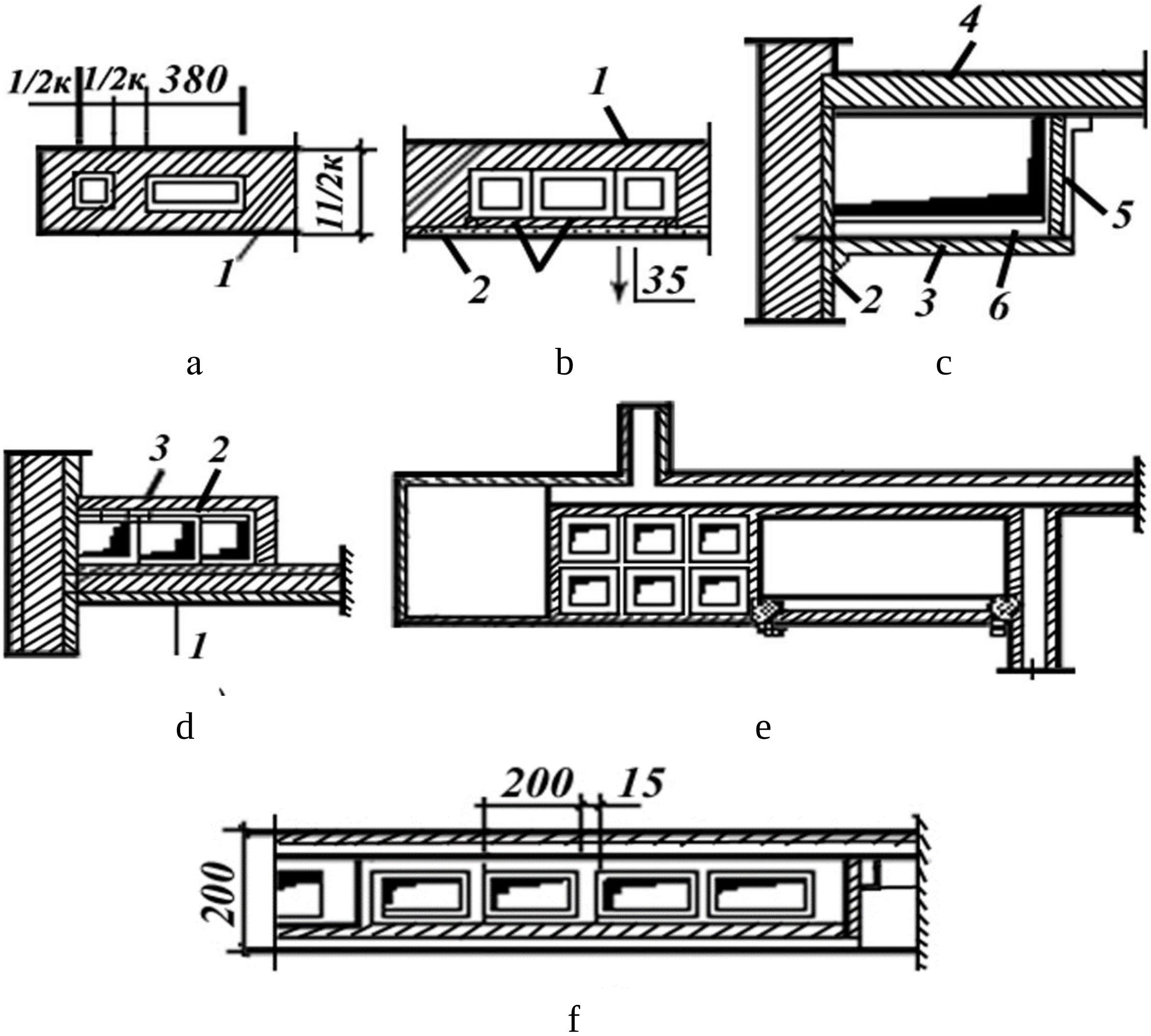
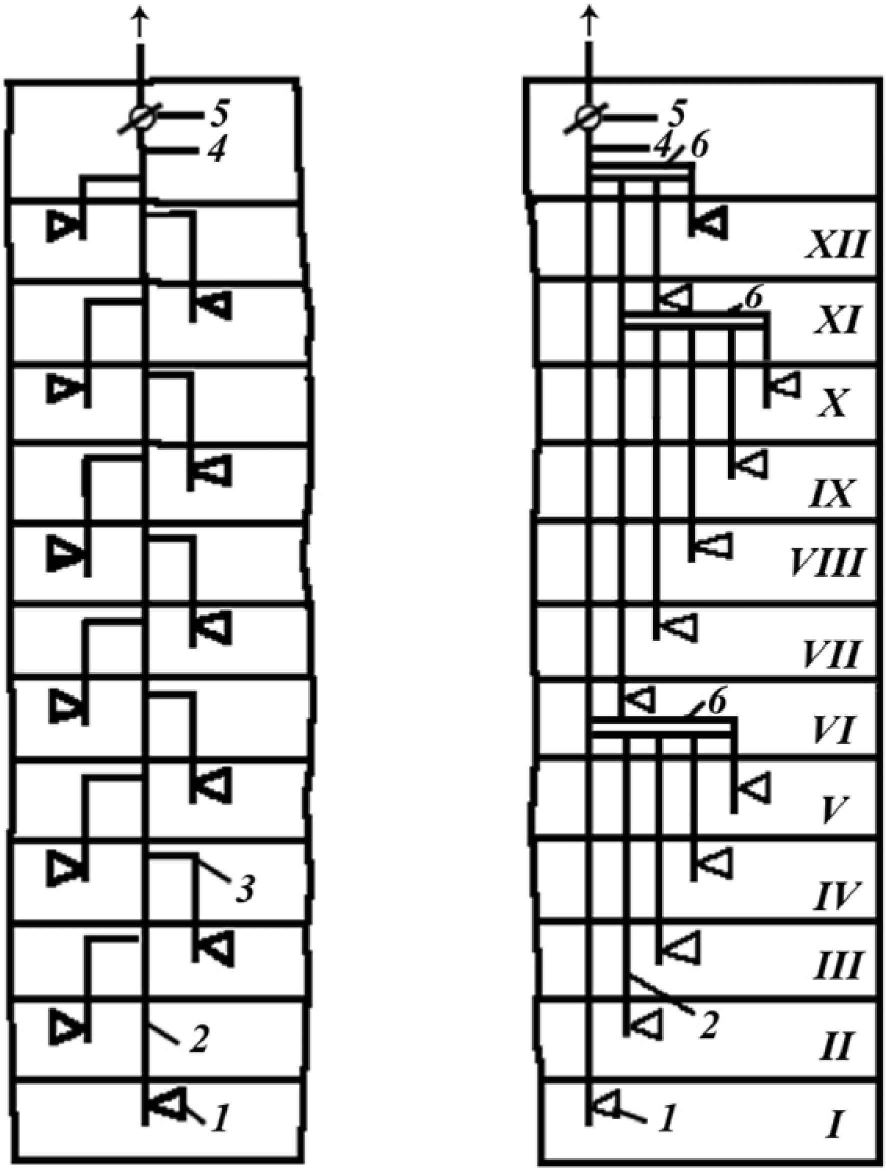


Fig. 1.1. Designs of Ventilation Channels and Ducts:
a is in brick internal walls; b is in the groove of the internal wall during closure with slabs; c is suspended duct under the ceiling; d is appended vertical channels; e is location of channels in internal walls with built-in wardrobes; f is channels made of dry plaster in partitions;
1 is brick walls; 2 is plaster; 3 is gypsum-fiber boards; 4 is flooring; 5 is teel suspension; 6 is fasteners sized 50×50×4 mm.



a b

Fig. 1.2. Arrangement of Natural Ventilation Channels in Multi-Storey Residential and Public Buildings (Scheme):
a is system with a vertical collector; b is system with a horizontal collector;
1 is opening for air removal; 2 is vertical collector; 3 is branch from the collector; 4 is exhaust ventilation shaft; 5 is regulating valve; 6 is horizontal collector.

Air movement occurs due to forces (draft) caused by the difference in air temperature at the inlet and outlet of the channel (warm air in the room is lighter than cold outside air). The natural gravitational pressure that drives air movement is calculated using the formula:

$$\Delta p_g = (\rho_{ext} - \rho_{in}) \cdot g \cdot H, \text{ Pa} \tag{1.1}$$

where ρ_{ext} is density of cold outside air, kg/m³, taken at an outside temperature of +5 °C (at higher temperatures, air exchange becomes insufficient); ρ_{in} is density of warm air in the room, kg/m³; g = 9,80665 м/с^2 – acceleration due to gravity; H is height between the inlet and outlet of the exhaust channel, m.

If the construction of taller structures occurs around the building, or if the building is being raised or high trees grow, the wind flow is significantly disturbed, which can cause aerodynamic coefficients to change signs. This leads to backdrafts in the ventilation system. It may stop functioning or start supplying air instead of removing it. Since exhaust grilles are not designed for air supply, there is a high probability of exceeding the allowable air speed in the service zone, resulting in drafts strong enough to knock lightweight objects off tables.

To stabilize and enhance the draft, deflectors are installed to convert wind energy into additional draft. In our country, during the warm season (when more air exchange is needed), wind speed is lower than in the cold season (when minimal air exchange is necessary). Therefore, this leads to the cooling of the premises. Consequently, deflectors cannot improve the operation of ventilation in heated premises and are only used for ventilating unheated spaces, such as basements and storerooms.

The efficiency coefficient $\eta_{v,g}$ of natural ventilation, which characterizes the ratio of energy expenditure on air movement to the available energy potential of that air, is determined as shown in Fig. 1.3.

For a channel height of up to 100 m (up to 33 storeys), $\eta_{v,g} < 0{,}0044$ or 0,44 %. For individual residential buildings up to three storeys, $\eta_{v,g} < 0{,}00044$ or 0,044 % – practically demonstrating negligible efficiency in using the energy potential of exhaust air.

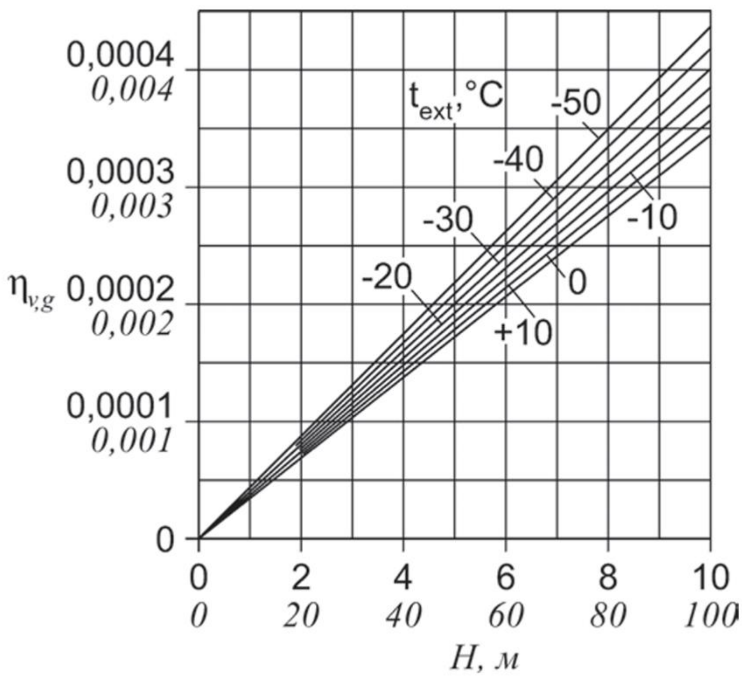


Fig. 1.3. Coefficient of Natural Ventilation Efficiency [4]

Disadvantages of this type of ventilation:

- Uncontrolled air exchange in the premises–excessive during the cold season, virtually absent during the warm season;
- The possibility of reversing the direction of the ventilation system's operation, resulting in unacceptably high air speeds;
- Absence of air filtration;
- Possible discomfort from cold incoming air;
- Limited range of action in the plan and a limited number of outlets (turns) due to the negligible existing pressure;
- High operational costs: increased load on the heating system due to the need to heat cold incoming air.

1.1.2 Combined Ventilation System

A significantly better option for ventilating a building is mechanical exhaust ventilation using domestic duct fans (see Fig. 8). The design of this ventilation system is similar to that of a natural ventilation system, but horizontal sections of varying lengths with any number of branches (turns) are possible. Air movement through the ducts is driven by the fan. Fans are selected according to the following principles:

- For sanitary units–exhaust fans linked with lighting, with a backdraft damper and automation based on a delay timer for shutdown;
- For bathrooms and showers–exhaust fans with a backdraft damper and automation based on a humidity sensor;
- For kitchens–exhaust fans with a backdraft damper and automation based on a humidity sensor with a manual start option.

The air supply is ensured by installing supply valves in the windows or walls of the building.

Disadvantages of this type of ventilation:

- Absence of air filtration;
- Possible discomfort from cold incoming air;
- High operational costs: increased load on the heating system due to the need to heat cold incoming air.

1.1.3 Mechanical Supply and Exhaust Ventilation System with Heat Recovery from Exhaust Air

The mechanical supply and exhaust ventilation system can be *decentralized*, in the form of wall-mounted ventilators, or *centralized*.

Decentralized ventilation systems allow for maintaining optimal microclimate conditions without significant interference in the interior of the premises. Such installations have several advantages [5]:

- Allow for reducing the energy load on cooling and heating systems without significant financial costs (noticeably cheaper compared to central systems–at both stages: installation and operation);
- Do not interfere with the interior of the premises (do not require an extensive duct system);
- Individual regulation is based on human presence in the premises.

Decentralized ventilation systems are represented by various types of ventilation equipment available in the Ukrainian market. They can be classified by the kind of heat exchangers–recuperators and regenerators.

Recuperative wall-mounted units include Prana, Breezy, and Vents systems. According to the manufacturer [6], Prana equipment is installed within the wall thickness at a height of no less than 110 mm from the ceiling. High efficiency of heat recovery (96%) is achieved through the use of a copper heat exchanger that is constantly washed on one side of the heat exchange surfaces by incoming air and on the other side by the exhaust air flow (see Fig. 1.4).

The drawbacks of the system include the possibility of freezing. Therefore, it is equipped with a defrosting mode and a freeze prevention feature that must be manually activated when the temperature drops below the freezing point of water, or if problems have already arisen. Additionally, the system has a passive mode with natural air movement, which can be used when the temperature difference between the external and internal air is up to 5 K.

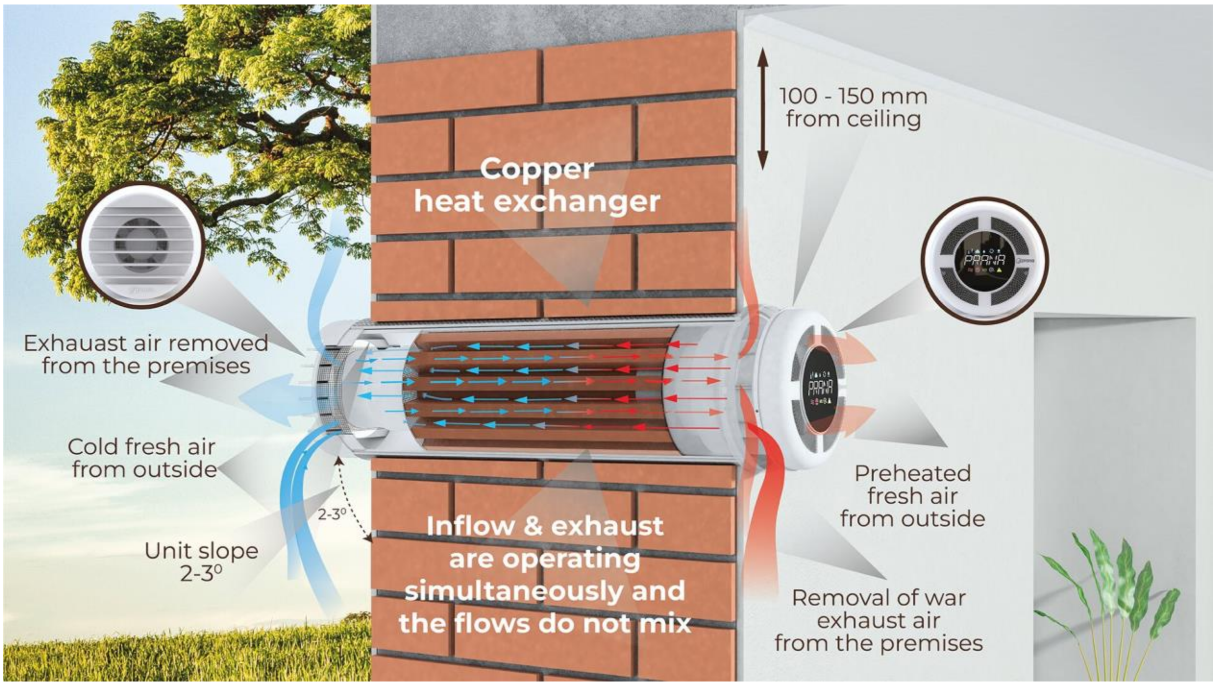


Fig. 1.4. The Prana installation works [6]

The Breezy recuperative installation (Fig. 1.5) consists of a telescopic duct of a specified length, which can be shortened as needed to fit the actual thickness of the exterior wall. Inside the duct, there are filters, high-efficiency fans with EC motors, flow separators for supply and exhaust air, a copper high-efficiency recuperator (up to 88 %), and electric heaters.

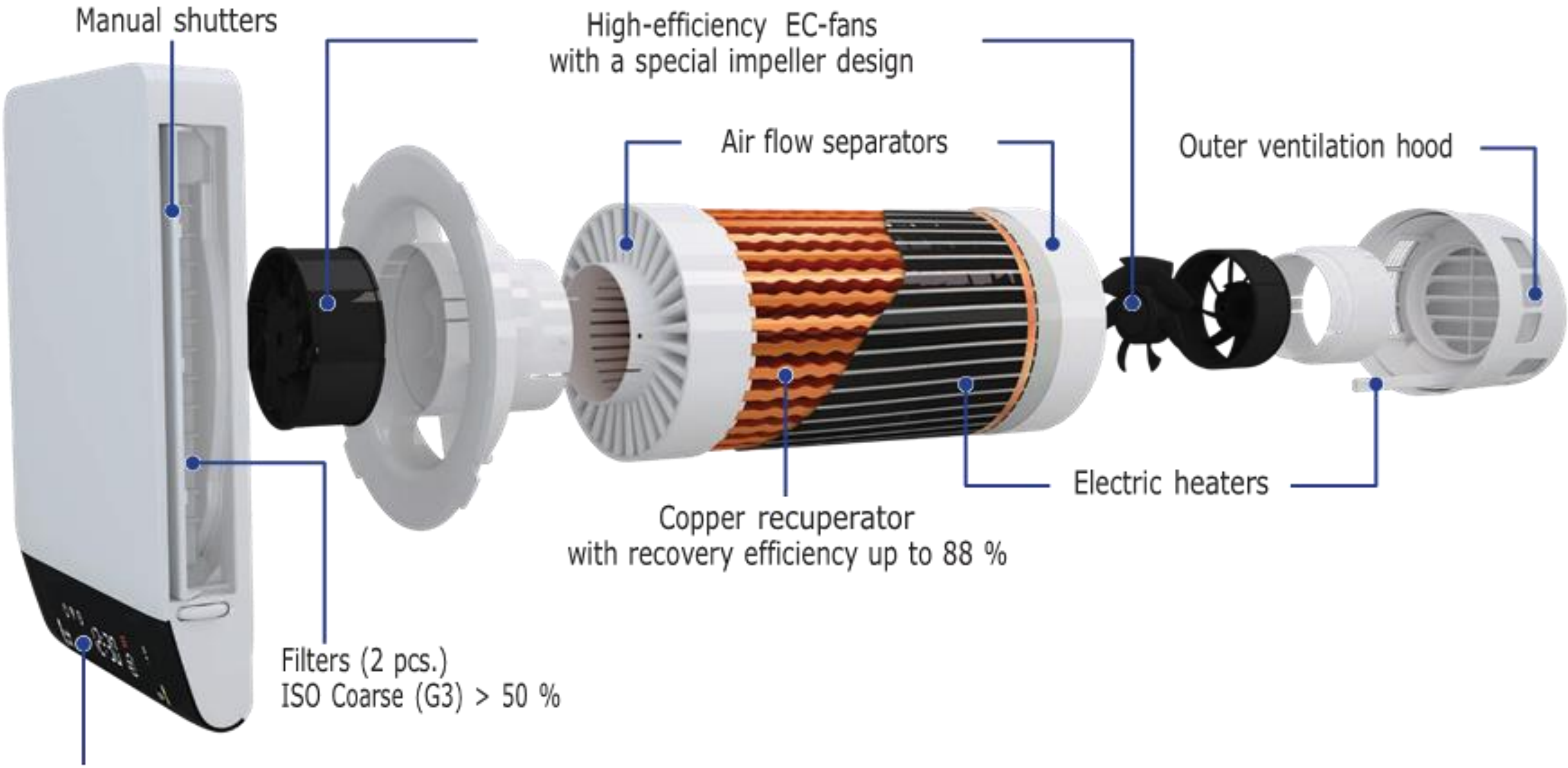


Fig. 1.5. Design of the Breezy installation [7]

Inside the room, the installation ends with a multifunctional panel with adjustable blinds to create highly efficient supply and exhaust jets. Externally, the opening is covered with a cap with a mesh to catch large dust particles (>10 microns).

During the operation of the Breezy installation (Fig. 1.6), filtered outdoor air is simultaneously supplied, and exhaust air is removed from the room. Due to the wall-mounted installation, no additional openings for air intake or removal need to be provided. This maintains the balance of air masses in the room. The exhaust air transfers its heat to the supply air in winter and cools in summer without mixing the streams. In this way, the device helps maintain an optimal temperature level in the room, reducing heating or air conditioning costs.

Fig. 1.6. Operating principle of the Breezy installation.

Regenerative wall-mounted supply and exhaust units are represented by the Vents Twin Fresh ventilators, which have an energy efficiency class of "A" and utilize the heat from the exhaust air in a ceramic regenerator. This equipment operates in a reversible mode - either for supply or for exhaust (Fig.s 1.7, 1.8). Installations are arranged in pairs and block each other to maintain the air balance in the apartment.

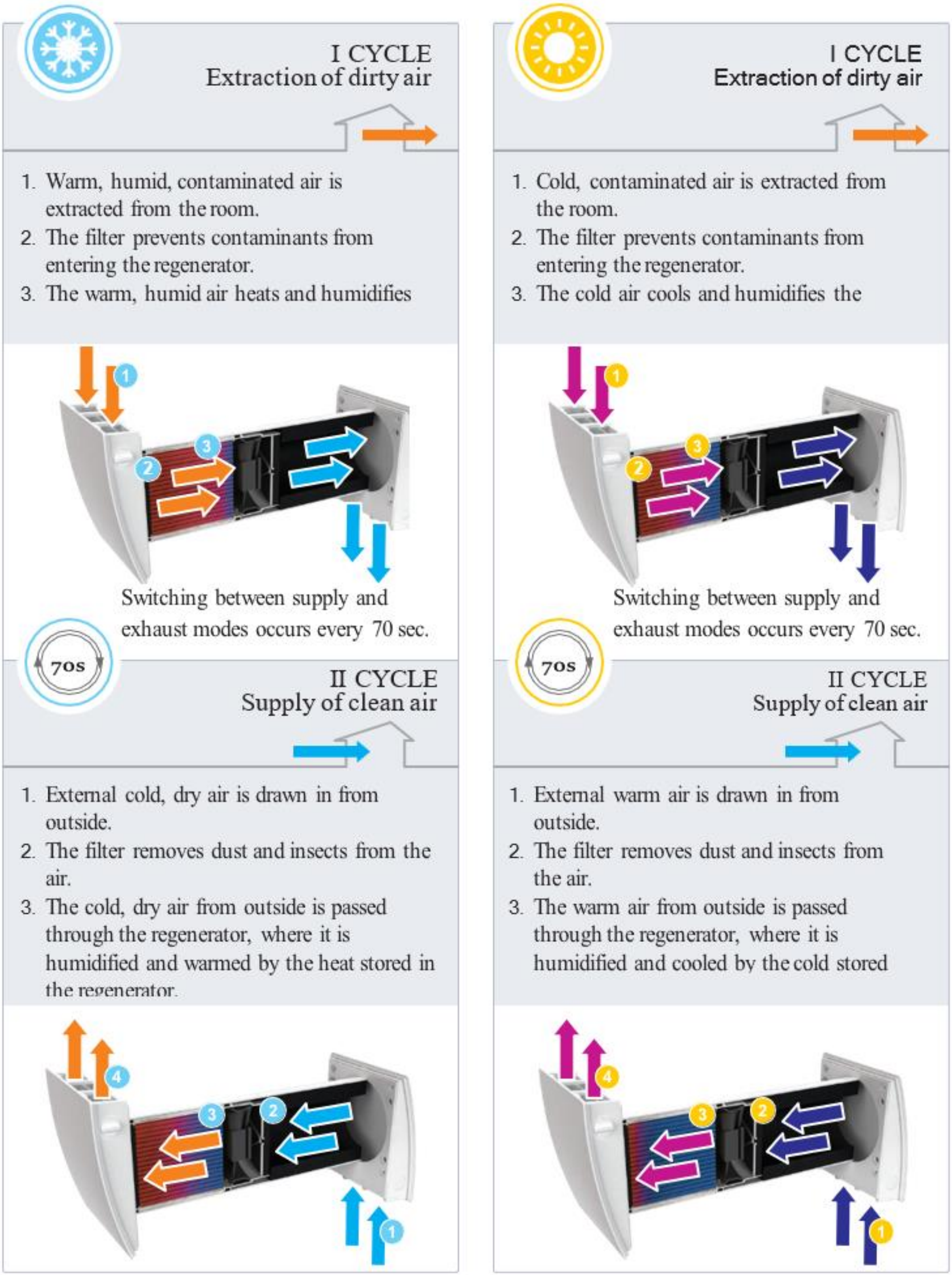


Fig. 1.7. Operating principle of the Vents Twin Fresh installation [8]

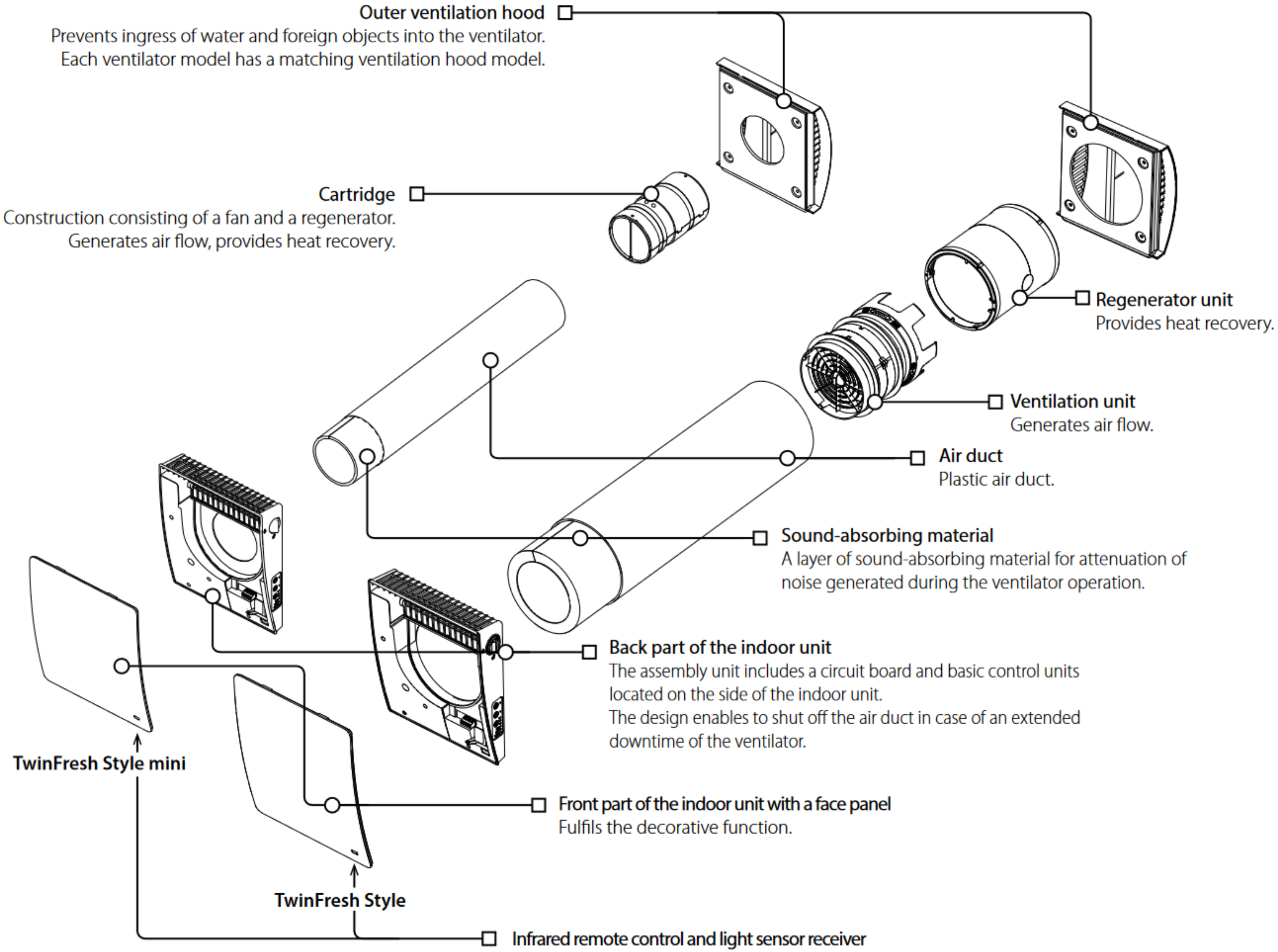


Fig. 1.8. Design of the Vents Twin Fresh installation [8]

The Twin Fresh consists of a telescopic duct (the total length of which is adjustable by changing the position of the inner duct within the outer duct), a fan unit with a chassis, and an external ventilation hood. Inside the telescope, filters and a ceramic energy accumulator (regenerator) are installed in the inner duct. For air supply and exhaust, a reversible axial fan with an EC motor is used.

The central mechanical ventilation system involves the use of a supply and exhaust unit with heat recovery, supply and exhaust ducts, and air intake devices (Fig. 1.9, Fig. 1.10). These elements of the system ensure ventilation of residential premises. In bathrooms, toilets, and kitchens, exhaust fans with backdraft dampers and automatic controls based on humidity sensors with the option of manual activation are installed. To maintain the balance of air masses, the supply and exhaust general exchange mechanical ventilation system is interlinked with local mechanical exhausts.

The advantages of such a ventilation system include:

- Supply air with acceptable concentrations of harmful substances and dust, and without excessive humidity;
- Automatic provision of necessary air exchange;
- Heating of the supply air to room temperature;
- Reduction of heat loss in the rooms through the utilization of heat from the exhaust air;
- Noise protection;
- No need to open windows in the rooms.

When choosing such systems, a significant economic benefit is observed during the prolonged operation of a building using supply and exhaust ventilation with heat recovery compared to natural or mixed ventilation. However, these systems have higher capital investments at the time of installation (Fig. 1.11).

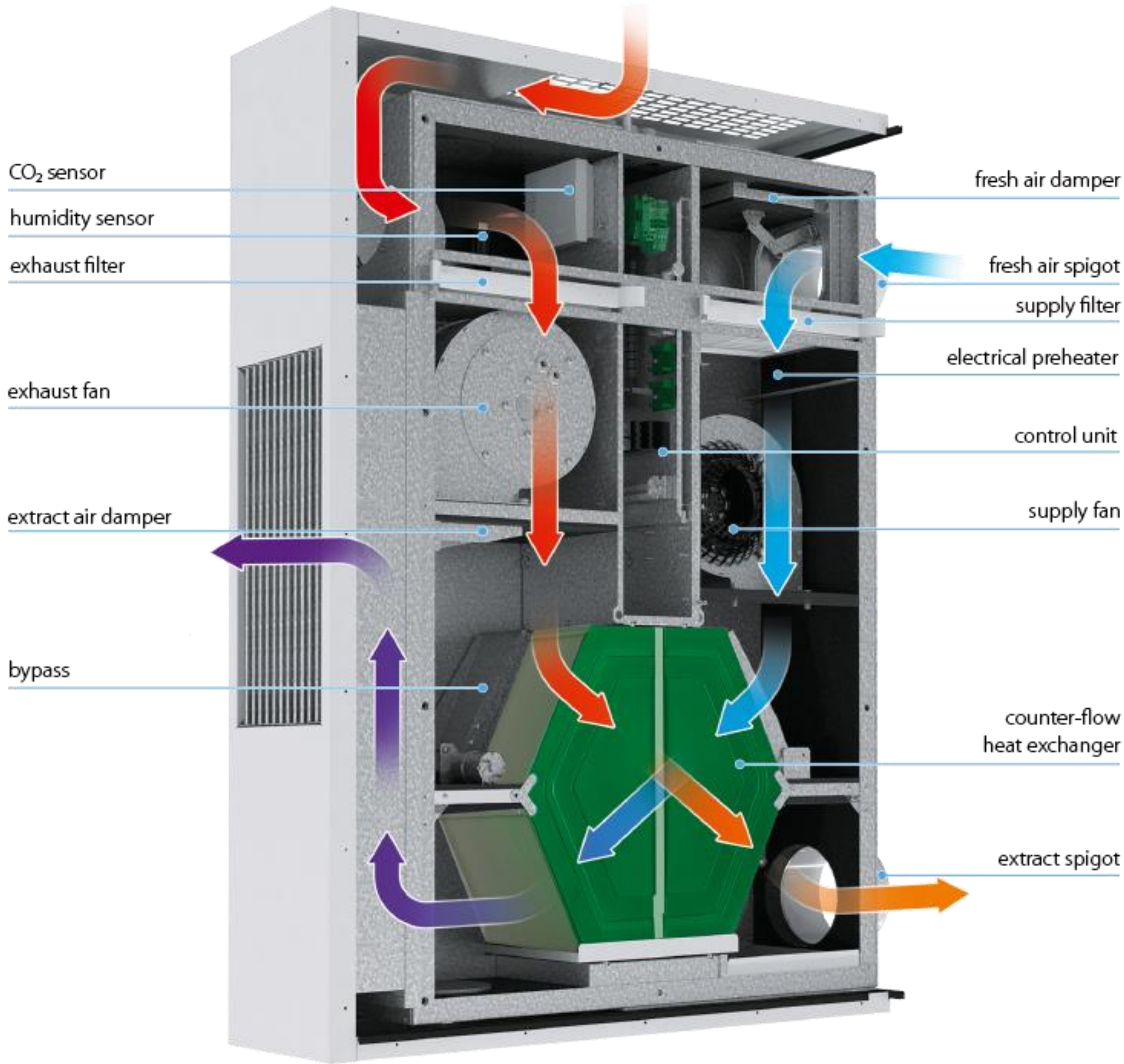


Fig. 1.9. Design of the supply and exhaust installation [9]

Fig. 1.10. Air distribution [9]

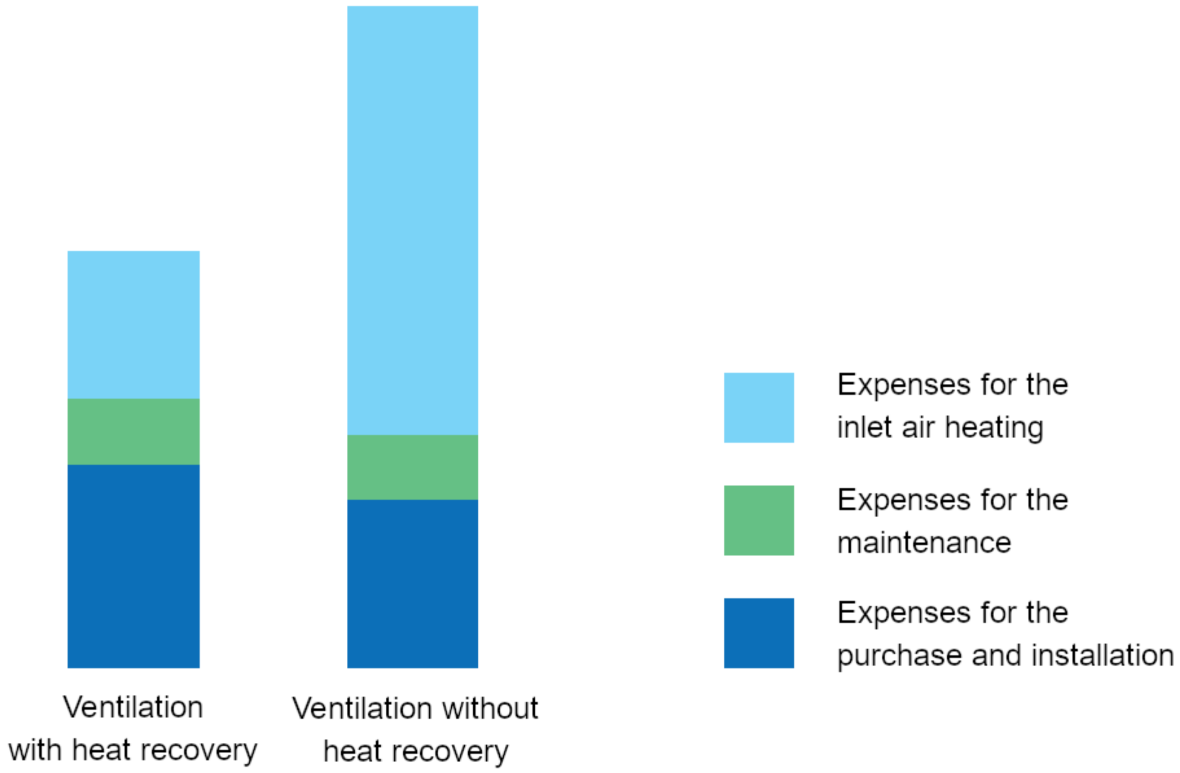


Fig. 1.11. Average total costs for ventilation over 5 years [4]

1.2 Ventilation of Public Spaces

There are a number of requirements for the location of ventilation equipment. It can be located either inside the building or externally or on the roof. Equipment in public buildings can be located directly in the premises it serves (with the exception of the requirements of section 7.9.2 [2, p. 51]), or in special rooms - ventilation chambers.

In public buildings, ventilation systems of floor and suspended types are most often used. The type of equipment depends on the amount of air it processes. If the airflow does not exceed 5,000 m^3/h, such equipment can be installed in suspended ceilings. However, if it is installed in the suspended ceiling of a corridor, it is necessary to provide for the installation of fire-resistant open dampers at the points where the ducts cross the walls separating the corridor and the serviced premises. The installation of these dampers is not required in premises with doors, the fire resistance class of which is not regulated [2, p. 51].

To reduce the spread of noise and vibration from the ventilation equipment, fans in the ventilation systems are connected to the ductwork using flexible connectors, and floor-mounted units are installed on vibration isolators. Noise suppressors are also installed in ventilation systems.

Air and air-thermal curtains are located near external doors, gates, and openings. They are provided under the following conditions:

- In permanently open openings of external walls of premises, as well as indoors and openings of external walls that do not have vestibules and are opened more than five times or for no less than 40 minutes per shift, in areas with a calculated external air temperature of minus 15 °C and lower during the coldest five-day period with a reliability of 0.92 according to DSTU – N B V.1.1-27;
- Near external doors of vestibules of public, administrative and household buildings when the number of people passing through the doors per hour is 400 or more;
- Other cases require justification (see section 7.7 [2, p. 48]).

Air and thermal curtains are classified by installation method (open and hidden mounting), air flow direction (vertical and horizontal), type of heat carrier (water, electric, freon, unheated), technical characteristics (industrial, for refrigeration chambers, for working windows of kiosks, pavilions, for openings of various sizes (width/height), and by type of execution (for revolving doors (vertical and horizontal), with exclusive design, etc.).

Directly in the serviced premises, ***air conditioning systems***, or ***air handlers*** are installed, which are used to treat the air in the room to achieve standardized microclimate parameters. An ***air handler*** is a unit or device designed to adjust the parameters of the incoming air to the required values for each room or zone [1, p. 25].

If the equipment generates noise during operation that exceeds the permissible level for the serviced room or if the conditions of the technological process do not allow it to be located in this room, the equipment is installed in ventilation chambers. A ***ventilation chamber*** is a specially designated room that meets the requirements for explosion-fire and fire safety (the category is determined by sections 7.10.2 and. 7.10.3 [2, p. 53]), intended for placing ventilation equipment. Such rooms must have an external exit (for air intake and removal), to stairwells, corridors, and serviced rooms. It is prohibited to arrange ventilation chambers under residential rooms, auditoriums and classrooms of educational institutions, audience halls of cinemas, theatres, and clubs, operating rooms and patient wards in medical institutions, sound recording studios, and other premises with high noise level requirements.

A necessary requirement for the placement of equipment in ventilation chambers is to ensure the ability to perform repairs, installation, and monitoring of the operation of ventilation systems. When air ducts cross the walls of the ventilation chamber, fire dampers should be installed.

It should be noted that equipment from exhaust systems that remove air with sharp or unpleasant odours (from restrooms, smoking rooms, etc.) is not allowed to be placed in the same ventilation chamber with supply equipment. It is also not allowed to install equipment serving residential premises in the same ventilation chamber as equipment from supply systems serving production and warehouse premises, public premises, and any exhaust system equipment.

Ventilation equipment located outside the building or on the roof must meet a number of requirements:

- Have appropriate climatic performance according to GOST 15150;
- Have appropriate mechanical performance according to GOST 30631;
- Comply with the general architectural solution of the building;
- Be fenced off to protect against unauthorized access and mechanical damage from wildlife (birds, rodents, etc.).

Placement of Air Ducts

Air ducts of ventilation systems are recommended to be placed as close to the ceiling as possible. To prevent condensation, air ducts transporting cooled air should be laid in thermal insulation. Ducts that are installed outside the building and air intakes to supply and supply-exhaust systems should also be insulated. The thickness of the insulation is determined by calculation.

Intake of Outdoor Air

Outdoor air should be taken from the cleanest zones and from the least heated air during the warm period of the year. In the absence of such zones, it is recommended to use green structures, for example, green coverings, walls, or terraces. The outdoor air intake device should not be located where the backflow of exhaust air or influence from other pollution sources, such as air with an unpleasant odour, is possible.

The location of the outdoor air intake should **not be closer than 8 m horizontally** from waste collection points, car parking zones (for three or more vehicles), driveways, loading areas, sewer ventilation openings, the tops of chimneys, and other similar pollution sources that create unpleasant odours. The air intake is not allowed to be placed on the facade of a building facing a busy street. If this is impossible, the air intake opening should be as high above the ground as possible.

The bottom of the outdoor air intake device should be located at **a height of at least 1 m above the level of stable snow cover**, which is determined according to the data from hydrometeorological stations or by calculation, and **no lower than 2 m above ground level**. The bottom of the outdoor air intake device located on the roof or covering of the building should be at **a height 1.5 times greater than the maximum possible height of the snow cover**. This height can be reduced if protective measures against snow cover are applied, such as a snow guard.

A tall building should be divided into separate ventilation zones, limited by a specified maximum height. The vertical distance D_{max} between the lowest and highest outdoor air intake openings in the same zone should not exceed the following value:

$$D_{max} = 600/(t_{in} - t_{ext}),\ \text{m} \tag{1.2}$$

where D_{max} is the vertical distance, m; t_{in} is the internal air temperature, °C; t_{ext} is the external temperature for the cold period of the year in the coldest five-day period with a reliability of 0.92, according to DSTU-N B V.1.1-27, °C.

In other cases, to prevent the influence of drafts, shut-off air dampers or similar devices should be provided.

Exhaust Air Discharge

Exhaust air should be discharged outdoors in a manner that does not pose a threat to human health or cause harm to the building or the environment. When locating air discharge points, the characteristics (quality) of the exhaust air, which depend on the type of premises and their use conditions, should be taken into account. Air discharge is usually carried out vertically upwards from the highest point of the roof.

The height of the ventilation pipe for the natural exhaust ventilation system, located at a distance equal to or greater than the height of a continuous structure that protrudes above the roof, should be accepted as follows:

- Not less than 0.5 m above a flat roof;
- Not less than 0.5 m above the ridge of the roof or parapet if the ventilation duct is located up to 1.5 m from the ridge or parapet;
- Not lower than the ridge of the roof or parapet if the ventilation duct is located at a distance of 1.5 to 3 m from the ridge or parapet;
- Not lower than the line drawn from the ridge down at an angle of 10° to the horizontal if the ventilation duct is located more than 3 m from the ridge.

The ventilation shafts of the natural exhaust ventilation system should be extended above the roof of the highest building to which the building with the natural ventilation system is adjacent.

For mechanical ventilation systems, the discharge of exhaust air outdoors is allowed through a device located in the wall of the building from rooms where the main sources of pollution are building materials, furniture, etc., as well as people (except for restrooms, smoking rooms, etc.), under the following conditions:

- The distance between the exhaust air discharge device and the neighbouring building is at least 8 m;
- The distance between the exhaust air discharge device and the outdoor air intake device on the same wall is at least 2 m (as a

rule, the exhaust air discharge device should be located higher than the air intake);

- The exhaust air flow rate does not exceed 0.5 m^3/s;
- The airspeed in the exhaust air discharge device is not less than 5 m/s.

In all other cases, exhaust air discharge devices should be located on the roof. The bottom of the exhaust air discharge device located on the roof or covering of the building should be at a height 1.5 times greater than the maximum possible height of the snow cover. This height can be reduced if protective measures against snow cover are applied, such as a snow guard.

1.2.1 Requirements for Ventilation Systems in Cultural, Entertainment, and Recreational Facilities

In regions with a calculated external temperature of the average coldest five-day period of -15 °C and below, air curtains or air-heat curtains should be installed in the openings for loading volumetric decorations with air intake from the upper zones of the warehouse.

In multi-hall cinemas with a total capacity of up to 800 seats, it is necessary to provide one supply ventilation system to serve several halls with the installation of fire-retardant dampers. For each hall, a zone air heating system (air handler) should be designed based on calculations.

Provided that the rooms maintain standardized air environment parameters (temperature, humidity, pollutant concentration levels – CO2) through ventilation means, the main general ventilation system should be accepted with air recirculation.

In full recirculation mode, the supply ventilation system operates only for the time necessary to heat the air in the halls before the start of the first screening [10, p. 48]. The full recirculation mode is prohibited during the presence of people in the rooms.

For a cinema hall with a capacity of 600 seats or more, zonal heating of supply air should be provided for lobbies and vestibules.

In cinema halls with a capacity of up to 800 seats, the supply of air should be carried out in compact jets with a maximum speed regulated by the permissible noise level in the halls and the standardized air mobility in the working zone.

In the audience hall, the air velocity at a level of 1.5 m near the nearest seats should not exceed 0.5 m/s, and the noise level from the outgoing air stream should be no more than 25 dBA.

Supply and exhaust ventilation systems should be provided separately for the audience complex and the club complex, for stage service rooms (platforms), as well as for administrative and maintenance premises.

In cinemas with continuous film screenings and in leisure club establishments at the place of residence, the specified distribution of systems is allowed not to be provided.

Independent supply ventilation systems should be provided for the following premises:

- Audience halls;
- Vestibules, lobbies, corridors, museum;
- Projection rooms;
- Light projection, lighting, sound equipment, sound engineer's room, commentator and translator booths;
- Artist dressing rooms, rehearsal and training rooms, rooms for the activities of artists and musicians, creative personnel, and artistic management, administrative and maintenance rooms, for club activities, technical communication, and broadcasting, production workshops.

In the audience halls of theatres and club venues with deep proscenium stages, the amount of air being exhausted must equal 90 % of the supply air (including recirculation) to ensure a 10 % positive pressure in the hall. No more than 17 % of the total air volume removed from the hall should be exhausted through the stage. When designing the audience hall and stage, it is necessary to provide for the installation of exhaust ventilation with natural inducement. Insulated dampers with remote control and condensate drainage trays must be installed in the exhaust shafts. Additionally, measures must be taken to prevent unorganized infiltration of external air into the halls through the exhaust shafts.

Separate exhaust systems should be provided for the following spaces:

- Sanitary facilities;
- The stage;
- Auxiliary rooms near buffets;
- Light projection rooms, lighting equipment rooms, sound equipment rooms, sound engineer booths, and booths for announcers and interpreters;
- Workshops;
- Storage rooms.

DBN V.2.2-16:2019 specifies separate exhaust ventilation systems for smoking rooms and allows their combination with ventilation systems from sanitary facilities; however, smoking in public places is currently prohibited. Therefore, such rooms are not designed.

In the design of club venues at residential locations, only natural exhaust from all rooms except for the audience hall and projection room is allowed. Separate exhaust and supply ventilation systems must be provided in projection rooms. Exhaust channels from rewinding rooms and translator booths may be connected to the exhaust systems.

Rooms housing ventilation equipment, air conditioning systems, compressors, and refrigeration installations should not be located directly behind the enclosing structures of the audience hall [10, p. 49]. This also applies to any other spaces where noise is generated.

1.2.2 Requirements for the Installation of Ventilation Systems in Food Service Enterprises (Restaurant Establishments)

Ventilation systems in food service enterprises (restaurants) that are integrated into or attached to other buildings must be designed separately from the respective systems of those buildings [11, c. 41]. The exhaust emissions from the ventilation systems of a food service enterprise that is integrated into or attached to a residential building must be discharged above the roof of the residential building.

Technological equipment with significant heat and moisture emissions must be equipped with local ***exhaust hoods*** serviced by local ventilation systems, which should be designed separately from the general exchange systems.

An exhaust hood is the terminal element of the system that captures air-containing pollutants directly at the point of their emission.

Local exhaust systems for technological equipment must be equipped with grease filters. It is recommended to utilize the heat from the exhaust air. However, operational experience with such systems shows that instead of cleaning or replacing them, they are often replaced without renewal. After this, the system remains functional for only a few months. Therefore, many designs do not incorporate heat recovery, resulting in a significant reduction in the energy efficiency of the building.

Exhaust hoods (local exhaust systems) should be installed directly above sources of hazardous emissions. Exhaust ventilation systems should be designed separately for the following spaces [11, p. 42]:

- Visitor areas (excluding toilets and washrooms);
- Hot kitchens and dishwashing areas;
- Local exhausts integrated into technological equipment;
- Production areas (excluding hot kitchens and dishwashing areas) and storage areas (excluding refrigerated chambers);
- Administrative offices;
- Toilets, washrooms, and showers;
- Refrigerated chambers for storing vegetables and fruits;
- Refrigerated chambers for storing food waste.

Air must be supplied to visitor areas and production spaces through separate supply systems. In designing air conditioning systems, central and local air conditioners with cooled supply and recirculated air must be used. Recirculation is only allowed within a single room. At the same time, the air exchange in the dining area, as well as in the hot kitchen and confectionery areas, should be determined taking into account the supply of cooled air to the premises. Local air conditioners must be used during the cold season to heat the air.

Entrance vestibules to visitor areas with a seating capacity of 100 or more should be designed with air curtains. Depending on the design task, air curtains may be designed for other entrances [11, p. 44]. To facilitate the installation, repair, and maintenance of ventilation equipment, installation openings, movable and stationary lifting transport devices, inspection hatches, condensate collection devices, and emergency drainage systems for water or other substances from the heat exchangers of ventilation equipment should be provided.

1.2.3 Requirements for the Installation of Ventilation Systems in Sports and Recreation Facilities

Separate supply and exhaust ventilation systems with mechanical inducement should be provided for [12, p. 62]:

- Sports halls, training halls in swimming pools, and spaces for physical education activities;
- Swimming pool bathing halls (including for recreational swimming and swimming lessons) and rowing pool halls;
- Showers, changing rooms for participants, massage rooms, and rest areas for swimmers;
- Service areas for administrative and engineering staff, coaching staff, and staff break rooms;
- Shooting ranges with firing zones in indoor and semi-open shooting ranges that have a wall with loopholes;
- Chlorination rooms and chlorine storage areas;
- Technical rooms (pump-filtering stations, boiler rooms, etc.).

In rooms for physical education activities integrated into residential buildings, natural ventilation with an unorganized supply is allowed. The exhaust ventilation system from sanitary facilities can be combined with the exhaust ventilation system from showers. Air removal from hall spaces, except for bathing halls, should be provided by exhaust systems with natural inducement.

In small settlements, residential areas, and rural areas, sports halls without spectator seating or with a capacity of no more than 100 may be designed with natural supply and exhaust ventilation that ensures a one-time air exchange per hour. In air heating systems for hall spaces combined with ventilation and air conditioning, the use of air recirculation is allowed. In this case, the volume of external air supplied should not be less than indicated in Table 23 [12 c. 59].

In sports halls with a capacity of more than 800 spectators and indoor ice rinks with spectator seating, independent air distribution systems should be provided for the spectator seating area and for the area where participants (competitors) are present. The organization of air exchange in indoor and semi-open shooting ranges should provide for the supply of supply air to the upper zone of the shooting gallery from the end wall (behind the shooting positions) across its entire width. Air removal in indoor shooting ranges should be provided under the ceiling of the firing zone (4-6 m in front of the firing line) for 2/3 of the total amount of air being removed, and from the lower zone (with exhaust openings located on both sides at a distance of 2 m from the firing line) for 1/3.

In semi-open shooting ranges, if there is a wall separating the shooting positions from the firing zone, air removal should be provided from both the upper and lower zones directly next to the wall. If intermediate firing ranges are arranged, exhaust systems must be provided in front of each firing line separately with the ability to switch the exhaust zones. The ventilation of chlorination rooms and chlorine storage areas should be designed for periodic operation. Air removal is carried out from two zones: the upper zone for 1/3 and the lower zone for 2/3 of the total exhaust volume.

Ventilation units must be placed outside these rooms. The control of the units should be carried out remotely from the starting devices located directly at the entrance to the room. The ventilation of the riding arena should be organized in such a way as to prevent condensation of steam due to the high humidity that occurs when a large number of horses are present. In stables, natural ventilation is typically provided, and the possibility of drafts is excluded. Therefore, for a corridor system, one gate is designed for 20-25 horses [12, p. 84].

1.2.4 Requirements for the Installation of Ventilation Systems in Educational Institutions

The supply of external air to educational rooms and exhaust from them should be provided by supply and exhaust units utilizing the heat of the exhaust air to warm the incoming air. This means employing means (such as recuperators, regenerators, intermediate heat exchangers) and methods (recirculation) for heat recovery.

The supply of external air through the upper casements of windows is allowed under the following conditions [13, p. 32]:

- In educational rooms with a capacity of up to 20 seats;
- In educational rooms with a capacity of up to 30 seats, if the educational institution is designed for areas where the normative (DBN B.2.5-67 and DSTU-N B.1.1-27) temperature of external air in winter (parameter B) is minus 18 °C or higher;
- In general secondary education institutions with up to 150 students.

If external air is supplied to educational rooms through the upper casements of windows, the exhaust ventilation from them should be designed with natural inducement without deflectors, calculated for a one-time exchange per hour.

Separate exhaust ventilation systems should be provided for the following spaces (groups of spaces): lecture halls, laboratories, educational workshops, rooms for course and diploma projects, reading rooms, assembly halls, physical education and sports halls, swimming pools, shooting ranges, dining rooms, medical rooms, film projection rooms, and sanitary facilities. Exhaust systems from food preparation areas and general toilets should be designed with class "Sh" ductwork. The exhaust air from these rooms must be organized above the roof of the highest building within a radius of 50 m.

Air removal from exhaust cabinets is allowed to be provided by a general system from one or several rooms, provided that explosion and fire safety is ensured.

In the design of heating and ventilation for physical education and sports halls, as well as dining rooms, the relevant design norms or corresponding sections of these guidelines should be followed. The ventilation of production rooms should also be designed in accordance with the norms of technological design.

1.2.5 Requirements for the Installation of Ventilation Systems in Retail Enterprises

In retail enterprises located in areas with a calculated cold season temperature (parameter B) below minus 15 °C, air-thermal curtains must be designed in the following cases:

- At customer entrances in stores with a sales area exceeding 150 m^2;
- At customer entrances in markets with a sales area greater than 600 m^2;
- At loading docks of grocery stores with a sales area greater than 1500 m^2;
- At loading docks of non-food stores with a sales area greater than 2500 m^2;
- In the presence of permanent workers in close proximity to the entrance opening;
- As specified in the project assignment in other cases.

Ventilation systems for stores integrated into buildings for other purposes or attached to them should be designed separately from the ventilation systems of these buildings [14].

If food and non-food products are sold in different halls of the same store, the ventilation systems of these halls must be separate. In areas where household chemicals are sold, recirculation is not allowed [14].

In the enclosing structures of refrigerated chambers, the installation of water supply and sewage pipelines, ventilation ducts, and electrical cables is not permitted.

SECTION 2.
VENTILATION EQUIPMENT

2.1 Air Handling Units (AHU)

An ***air handling unit (AHU)*** consists of air dampers (shutters), filters, a recirculation section, an exhaust air heat exchanger, heating and/or cooling sections, flexible connectors, and the fan itself (Fig. 2.1).

Types of air handling units:

- *Supply Units* provide processed fresh air to the room.
- *Exhaust Units* remove processed (e.g., local exhaust units for grease traps, and dust collectors) or unprocessed air from the room.
- *Supply and Exhaust Units* handle the processing and delivery or removal of air from the room and may include various types of heat exchangers and/or air recirculation sections.

2.2 Fans

A ***fan*** is a rotating blade machine that increases the specific energy of air or other gases, creating a continuous flow at relatively low compression, not exceeding 1.3 [1, p. 4]. In ventilation and air conditioning systems, two main types of fans are used: radial (centrifugal) and axial (axial). Fans can have either continuous (EC motor) or stepwise (AC motor with speed controller) airflow regulation.

A ***radial fan*** is a type of fan where the direction of the meridional velocity of the gas flow at the inlet to the impeller is parallel, while at the outlet from the impeller, it is perpendicular to the axis of rotation (Fig. 2.2) [1, p. 4]. Radial fans can have either a scroll housing or a straight-through design.

Note: Depending on the design of the impeller, fans may be single-inlet or double-inlet.

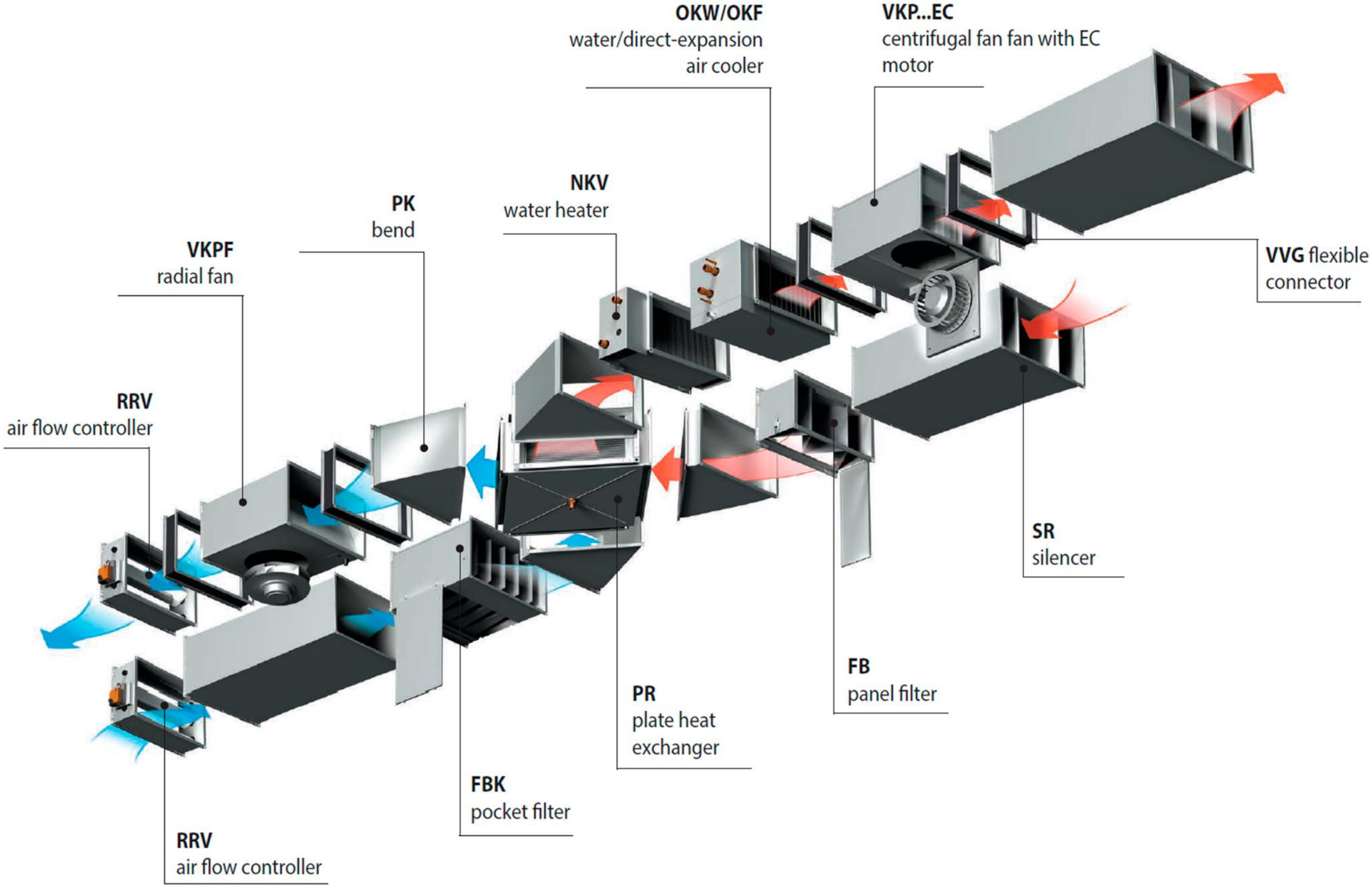


Fig. 2.1. Sections of AHU

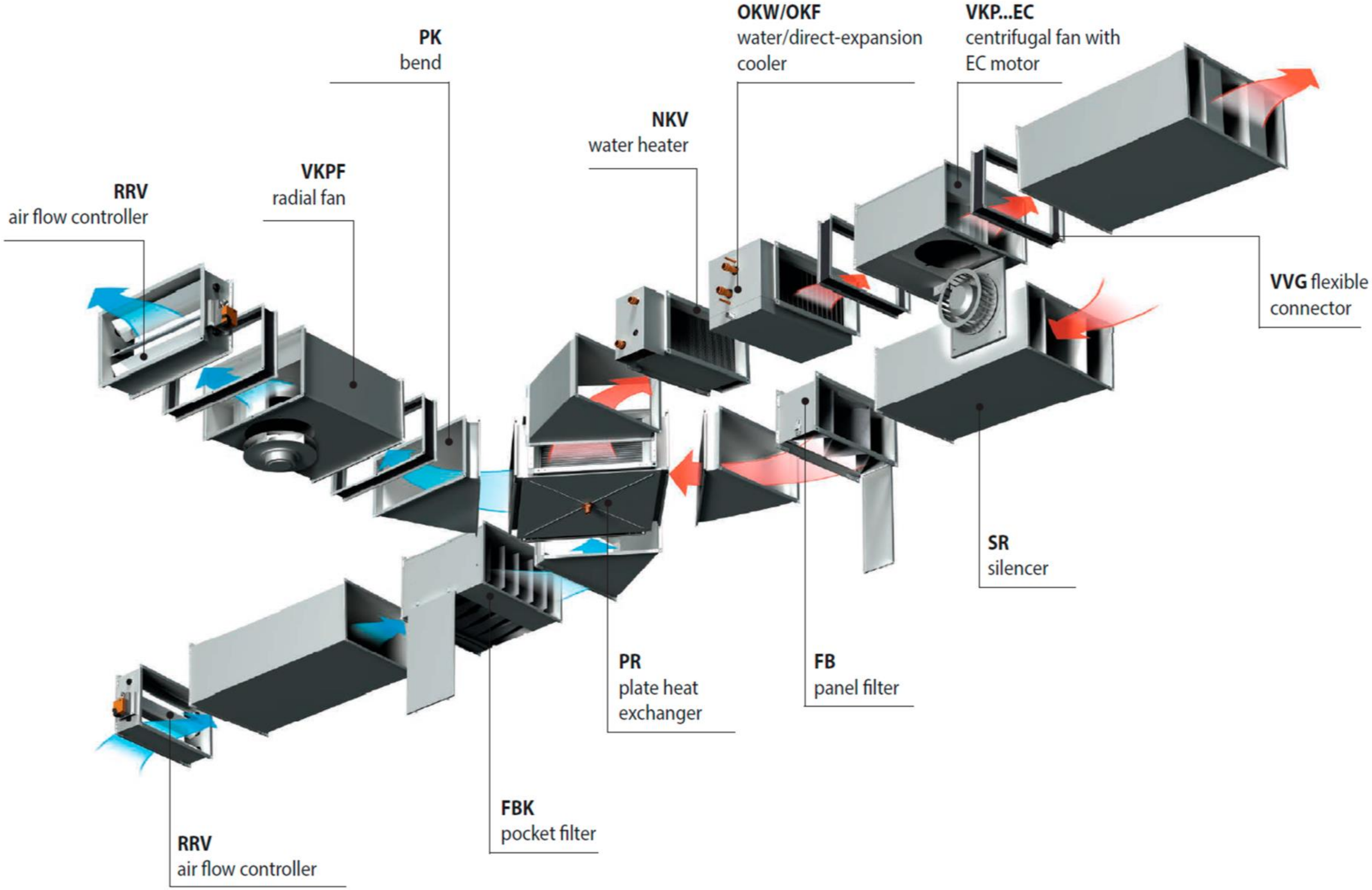
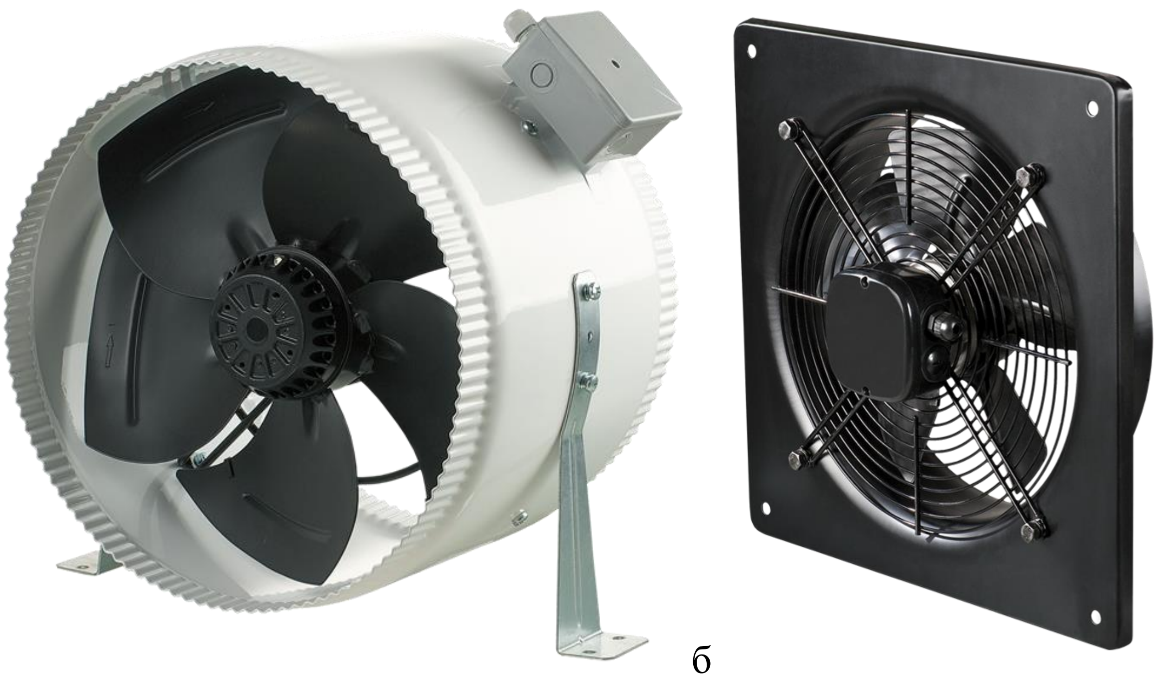


Fig. 2.1. Sections of AHU

Fig. 2.2. Radial fans

An ***Axial Fan*** is a fan in which the direction of the meridional velocity of the gas flow at both the inlet and outlet of the impeller is parallel to the axis of rotation (Fig. 2.3).



a б

Fig. 2.3. Axial Fan:
a – Duct-type; б – Wall-mounted type.

2.3 Heat Exchangers

A ***heat exchanger*** is a device used to recover excess heat or cold from a technological process or exhaust air, with the purpose of utilizing it to heat or cool incoming air [1, p. 13].

Types of heat exchangers:

- *Regenerative* (heat exchange through a separating wall);
- *Recuperative* (intermittent washing of a solid body by streams);
- *With Intermediate Heat Carrier* (two recuperative heat exchangers connected by an intermediate heat carrier loop);
- *Contact* (direct contact of air with an intermediate heat carrier, such as water);
- *With Heat Pipes* (two air ducts connected by heat pipes, where intense heat exchange occurs due to the natural evaporation and condensation of the refrigerant).

Efficiency of Heat Exchangers

The temperature efficiency coefficient of a heat exchanger is determined by the formula::

$$\varepsilon = \frac{t_2 - t_1}{t_3 - t_1} \tag{2.1}$$

where t_1, t_2, t_3 are temperatures depending on the placement scheme of the recuperator in the system, in °C (Fig. 2.4).

Heat exchangers are most effective during the cold season. During warmer periods, in systems without cooling, heat exchangers heat the incoming air due to the temperature difference between the exhaust and supply air. In such cases, bypassing the ventilation system should be considered. If the space is equipped with an air conditioning system, and the air is removed from the space is cooler than the outside air, the heat exchanger will recover cold from the exhaust air.

The most common configurations in Ukraine, with corresponding modifications to the formula (3), are shown in Table 2.1 and Table 2.2.

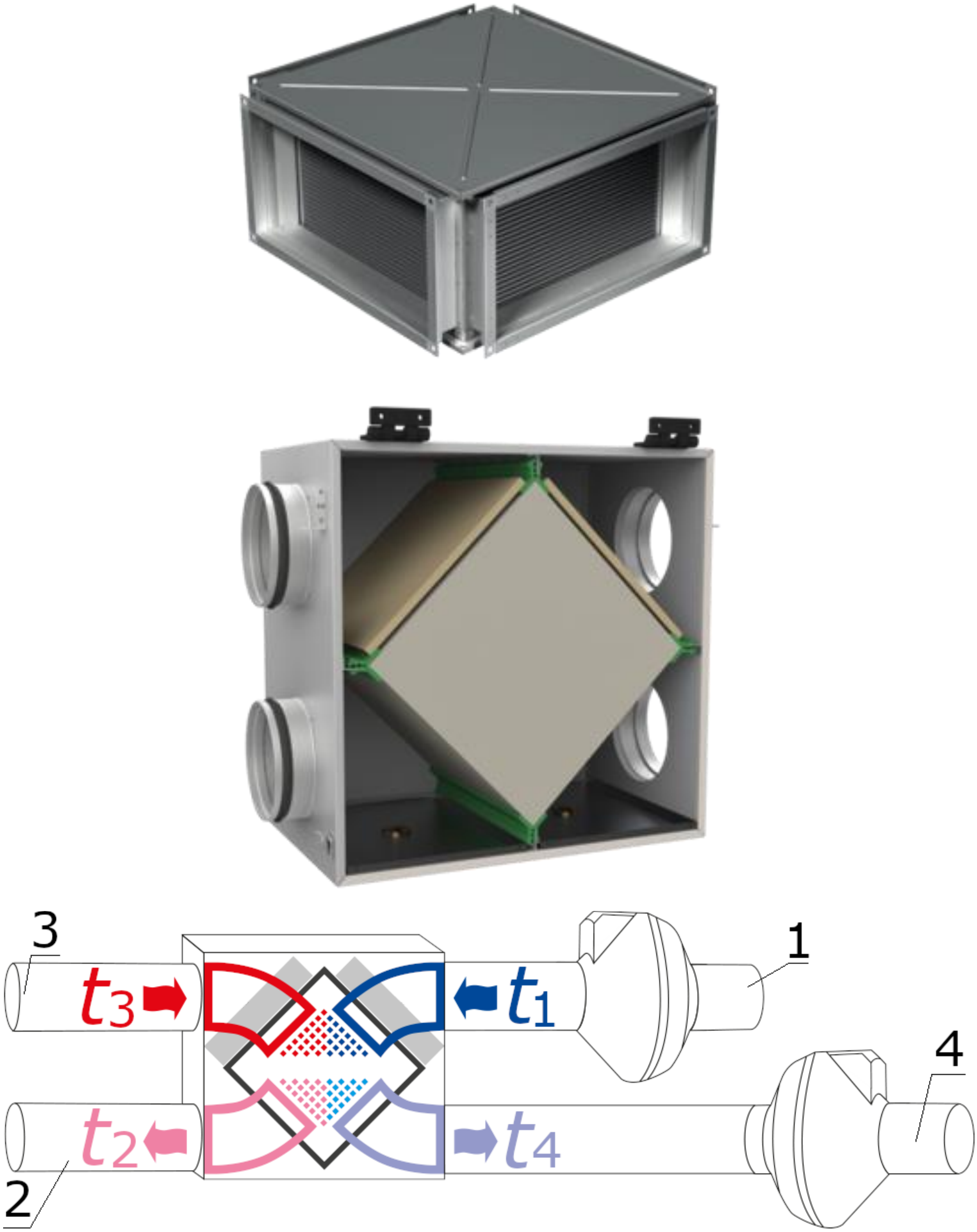


Fig. 2.4. Plate Recuperators:

1 – Supply air to the recuperator; 2 – Exhaust air after the recuperator; 3 – Exhaust air to the recuperator; 4 – Exhaust air after the recuperator.ластинчасті рекуператори:

Table 2.1

Temperature Efficiency Coefficient of Heat Exchangers for Typical Configurations of Supply and Exhaust Systems Without Cooling

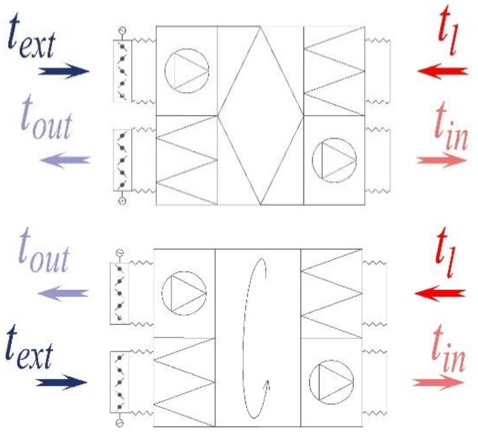
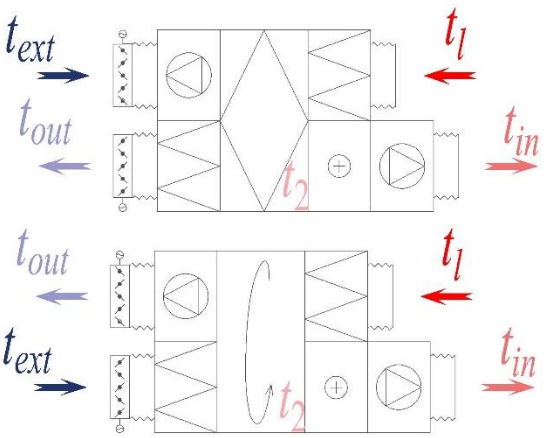
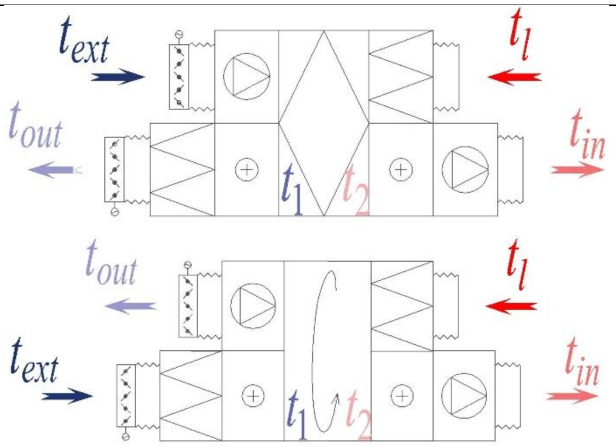
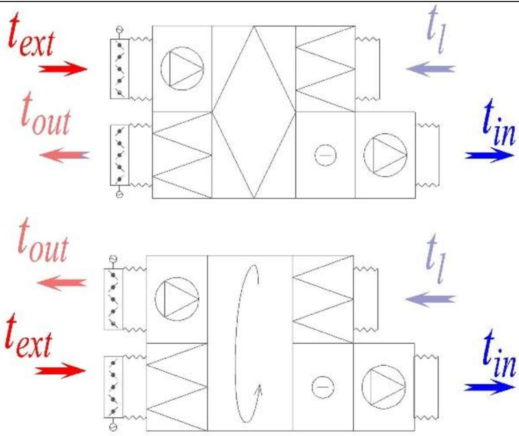
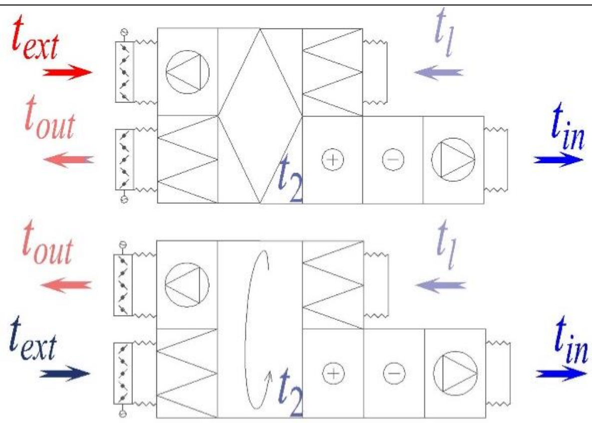
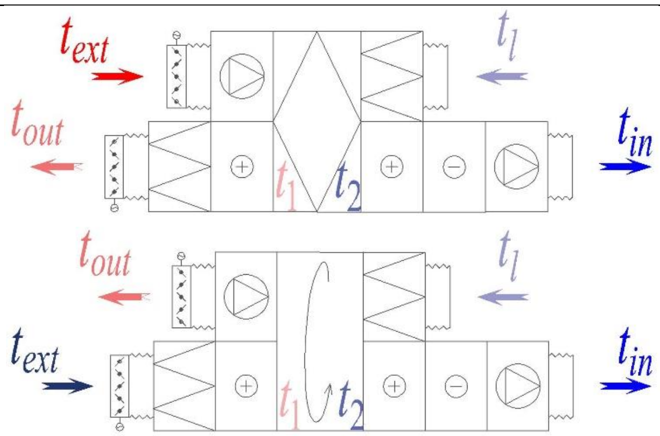
System Configuration	Temperature Efficiency Coefficient, ε	
	Warm Season	Cold Season
1	2	3
	Inefficient $\frac{t_{in} - t_{ext}}{t_l - t_{ext}}$	Efficient $\frac{t_{in} - t_{ext}}{t_l - t_{ext}}$
	Inefficient $\frac{t_{in} - t_{ext}}{t_l - t_{ext}}$ $t_{in} = t_2$	Efficient $\frac{t_2 - t_{ext}}{t_l - t_{ext}}$
	Inefficient $\frac{t_{in} - t_{ext}}{t_l - t_{ext}}$ $t_{ext} = t_1$ $t_{in} = t_2$	Efficient $\frac{t_2 - t_1}{t_l - t_1}$

Table 2.2

Temperature Efficiency Coefficient of Heat Exchangers for Typical Configurations of Supply and Exhaust Systems With Cooling

System Configuration	Temperature Efficiency Coefficient, ε	
	Warm Season	Cold Season
1	2	3
	Efficient $\frac{t_{ext}-t_{in}}{t_{ext}-t_l}$	Efficient $\frac{t_{in}-t_{ext}}{t_l-t_{ext}}$
	Efficient $\frac{t_{ext}-t_2}{t_{ext}-t_l}$	Efficient $\frac{t_2-t_{ext}}{t_l-t_{ext}}$
	Efficient $\frac{t_1-t_2}{t_{ext}-t_l}$ $t_{ext}=t_1$	Efficient $\frac{t_2-t_{ext}}{t_l-t_{ext}}$

Regenerative heat exchangers are widely used in modern ventilation systems. They are divided into counterflow shell-and-tube exchangers (Fig. 1.4) and crossflow plate recuperators (Fig. 1.5, Fig. 1.8). In a *counterflow heat exchanger*, air streams move towards each other and are separated by a heat transfer surface, through which heat recovery occurs. The *crossflow plate recuperator* (Fig. 2.4) is characterized by a cross-shaped airflow through the channels of the heat transfer surface.

Recuperators are used when air streams must be separated, such as when removing air containing harmful contaminants or odours. The air passing through the recuperator should not contain solid, fibrous, aggressive, or explosive impurities that could damage or destroy it.

The main characteristics of plate recuperators include their efficiency and the resistance they create in the air duct system.

Rotary Heat Exchangers (Fig. 2.5) belong to the class of regenerative heat exchangers. These devices are widely used in supply and exhaust ventilation systems. In rotary heat exchangers, heat transfer from the exhaust air to the supply air is achieved through a moving matrix with various types of coatings. The regeneration process depends on the temperature difference between the outside and the exhaust air.

Fig. 2.5. Rotary Heat Exchangers

In a rotary heat exchanger, gas leakage from the high-pressure stream to the low-pressure stream (2-3% of the total flow) is possible due to the necessary gap between the rotating rotor and the housing elements. These leakages can be partially minimized using a brush seal located around the rotor's circumference.

Complete isolation of the inlet and outlet air streams is technically impossible. However, this is not a major concern since only about 5% of mixing occurs. Rotary heat exchangers are equipped with variable-speed electric drives, which maintain optimal efficiency and regulate the level of energy recovery.

The matrix of a rotary heat exchanger consists of two layers of aluminium foil, smooth and corrugated, alternately applied to each other. The regeneration efficiency varies with the height of the corrugated strip and the rotor speed. Reducing the heat exchange surface area and operating the rotor at 10 RPM can reduce energy consumption by 80%.

The device has a cylindrical shape with a housing made of galvanized steel. The construction also includes a drive mechanism with a belt for rotation, axial bearings, a sensor to monitor rotor rotation, and a sealing strip for isolating air flows. The rotor is driven by a V-belt drive. If the regenerator operates at high temperatures, the electric motor is placed outside the heat exchanger housing, and a chain is used instead of the belt.

The structural design of rotary regenerators can be either horizontal or vertical.

Several modifications of recuperators are available:

- *Standard Design*: This involves dividing the regenerator into 4, 6, 8, or 12 sectoral parts. Such recuperators are used for removing excess heat from exhaust air and are known as condensation rotors that transfer moisture when the exhausted air masses are below the so-called “dew point.” The main rotor matrix is made from aluminium resistant to seawater.
- *High-Temperature*: Heat exchangers designed for removing sensible heat from air streams with temperatures up to +250°C.
- *Enthalpy*: Used for removing total thermal energy with additional moisture transfer.

The coating of the rotary drum material can vary. Based on this characteristic, recuperators are classified as follows:

- *Condensation Type*: The rotor is an uncoated aluminium drum that primarily transfers thermal energy. It does not significantly transfer moisture energy from the air stream.
- *Hygroscopic Type*: The aluminium drum cells are covered with a hygroscopic coating with sorption properties. The rotating drum collects moisture and transfers it from one stream to another, thus recovering moisture and latent heat.
- *Sorption Type*: Devices that increase the efficiency of the enthalpy recuperator using innovative sorbents like silica gel, which has a large surface area (800 m^2/g) and high moisture absorption capacity.
- *Epoxy Coated*: Coating is used to protect the aluminium drum from harmful effects of chemical compounds in the air, such as high chlorine content in pool air, increased salt concentration in marine air, or corrosive vapours in chemical production.
- *Antibacterial Coated*: Coating that effectively combats over 600 types of microorganisms, usually applied to enthalpy rotors or those with an epoxy coating.

2.4 Heaters and Coolers

A **heater** is a heat exchanger designed to heat air passing through it by utilizing heat from external sources [1, p. 11]. Heaters are classified as follows:

- *By heat carrier type:* water, electric, refrigerant;
- *By construction of the heat exchange surface on the air side:* smooth tubes, finned tubes;
- *By the nature of the heat carrier movement in tubes:* single-pass, multi-pass;
- *By material of tubes and fins:* steel, copper, aluminium, and their combinations;

- *By type of finning on the heat exchange surface:* plate, spiral-wound, spiral-staggered, etc.;
- *By the number of rows of tubes in the direction of airflow:* single-row, multi-row.

Water and electric heaters are most commonly used in ventilation systems (Fig. 2.6, Fig. 2.7).

Fig. 2.6. Water heaters

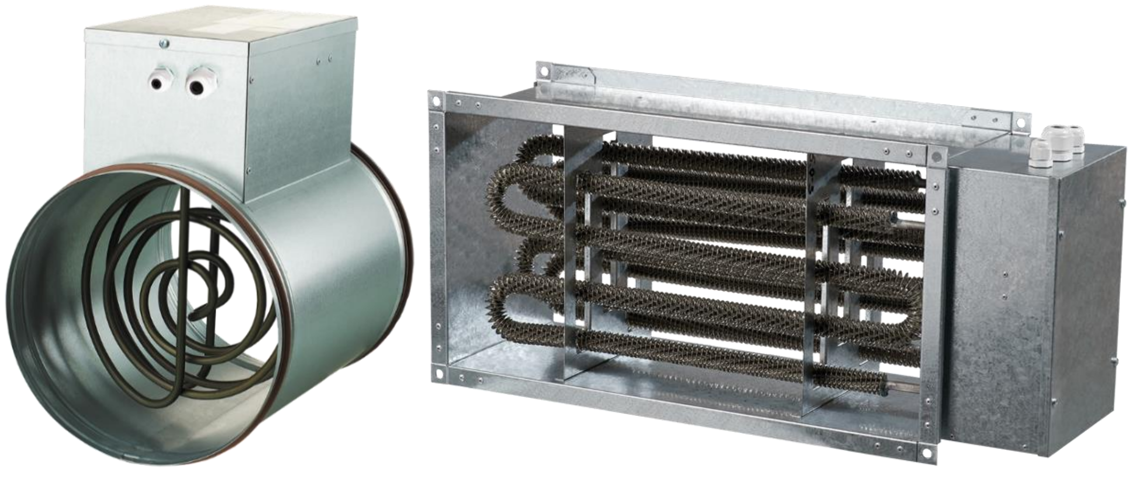


Fig. 2.7. Electric heaters

Prevention of Heater Freezing

Causes of Freezing:

- Low heat carrier flow rate (up to 0.2 m/s);
- The actual air flow rate exceeds the design rate;
- Contamination of the heat exchanger tubes;
- Malfunction of the insulation valve.

Preventive Measures:

- Install a circulation pump in the heater's piping system (Fig. 2.8);
- Ensure that the heat transfer surface area does not exceed 10%;
- Heaters with horizontal heat transfer tubes should be positioned exactly horizontally; those with vertical tubes should be positioned exactly vertically;
- The flow scheme for the heat carrier and air should be "direct-flow-cross";
- Install air vents at the highest points of the heater piping system;
- Provide automatic protection against heat carrier freezing;
- Ensure the heat carrier flow rate exceeds 0.2 m/s.

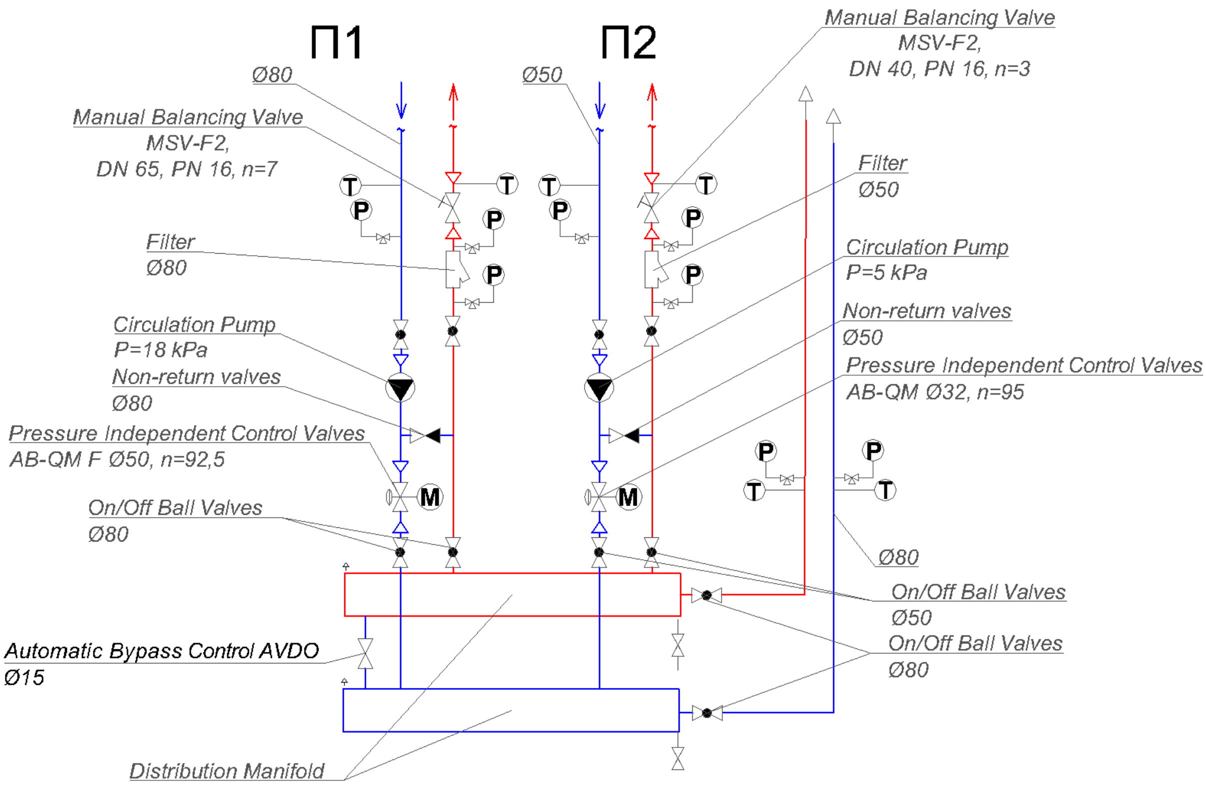


Fig. 2.8. Schematic Diagram of Water Heater Piping for Ventilation Systems

Heat Exchanger Calculation

1. Determine the required heating power of the heater for air supply using the formula:

$$Q = L \cdot \rho \cdot C_{air} \cdot (t_{in} - t_{ext}), W \quad (2.2)$$

where L is volumetric flow rate of supply air, m^3/s; ρ is density of external air, kg/m^3; C_{air} is pecific heat capacity of air, C_{air} = 1005 J/(kg•˚C); t_{in} is temperature of the air supplied to the room, ˚C; t_{ext} is temperature of the coldest five-day period with a probability of 0.92 for the design city, ˚C.

2. Determine the mass flow rate of the heating medium for the water heater:

$$W = Q/(C_w \cdot (t_\text{г} - t_\text{o})), \text{kg/s} \quad (2.3)$$

where C_w is pecific heat capacity of water, C_w = 4190 J/(kg•˚C); $t_\text{г}$ is temperature of the hot heating medium, ˚C; t_o is temperature of the cooled heating medium, ˚C.

3. Knowing the flow rate of the heating medium, the pipe cross-section for connecting the water heat exchanger can be selected, considering the recommended velocity range of 0.25-1.5 m/s.

4. The live cross-section of the heater section is selected based on the recommended airflow velocity range of 2.5-3.0 m/s.

Air Cooler is a heat exchanger for reducing air temperature and also for lowering air humidity by utilizing cold from external sources [1, p.11]. Air coolers can be either water-based or refrigerant-based (Fig. 2.9).

They differ in the type of cooling medium – water, aqueous solution (water-propylene glycol, water-ethylene glycol), or refrigerant (e.g., R-410A or R-32). Pipes carrying water or its solution are made of steel. Pipes carrying refrigerants are made of copper with diameters of 6.35 mm, 9.52 mm, 12.7 mm, 15.88 mm, 19.05 mm, and 22.23 mm. Both copper and steel pipes are insulated thermally, with the insulation thickness determined by calculation.

Fig. 2.9. Refrigerant-based and Water-based Air Coolers

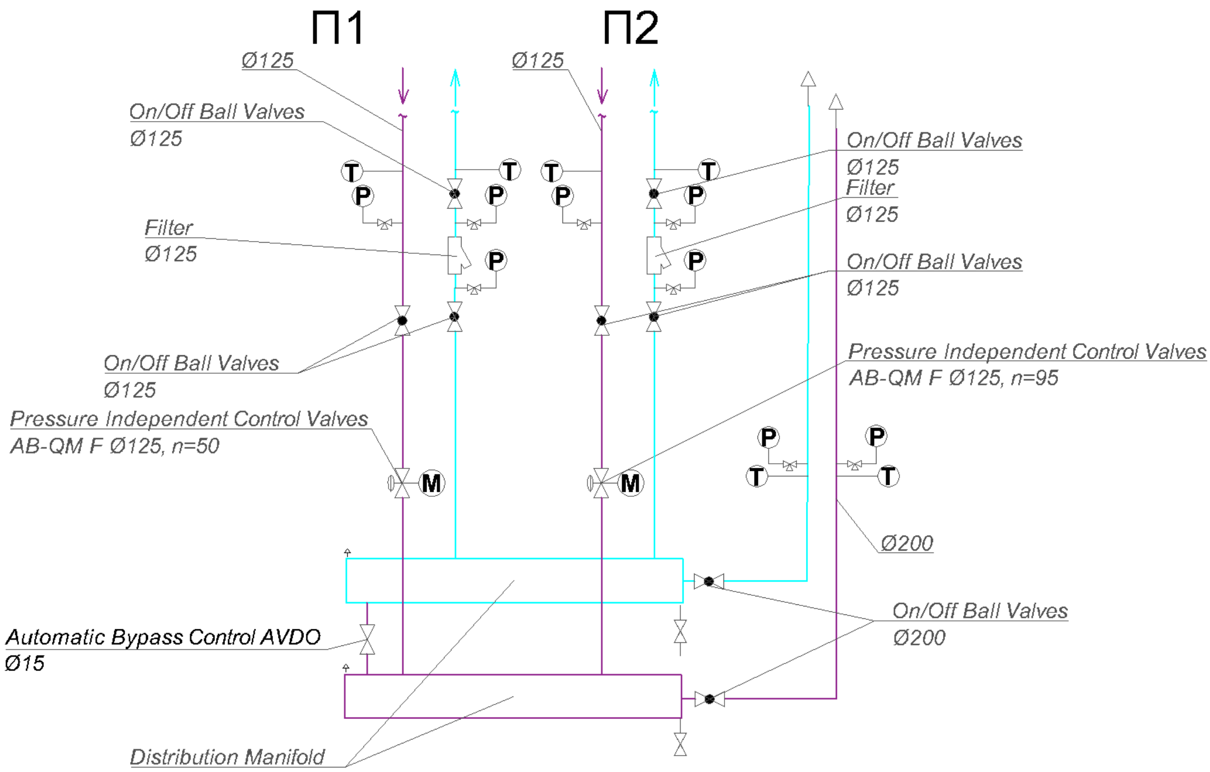


Fig. 2.10. Fig. 2.10. Schematic Diagram of the Piping for Water-based Air Coolers in Ventilation Systems

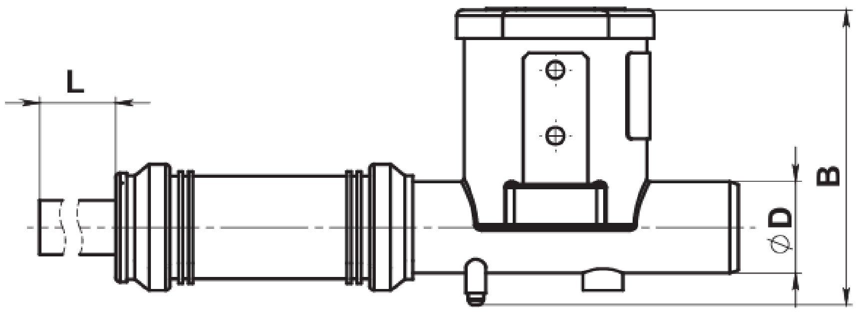
During the air cooling process, condensate forms on the tubes of the air cooler. To prevent the condensate from entering the duct network with the air, drip trays are installed. The condensate collected by these trays is directed to the drainage system.

2.5 Drainage System

An important requirement for ventilation system design is the effective drainage of condensate from rotary regenerators and air cooling sections.

Condensate collection trays are incorporated into the ventilation unit designs to gather the condensate.

When draining condensate from the ventilation system, it flows through a flexible PVC pipe connected by a coupling, leading to a siphon (Fig. 2.11). This siphon is equipped with a mechanical sealing device that prevents odours from the sewage system from entering the ventilation system after the trap has dried out (Fig. 2.12).



Dimensions, mm	
ØD	32
B	103
L	1000

Fig. 2.11. Siphon Connection Kit

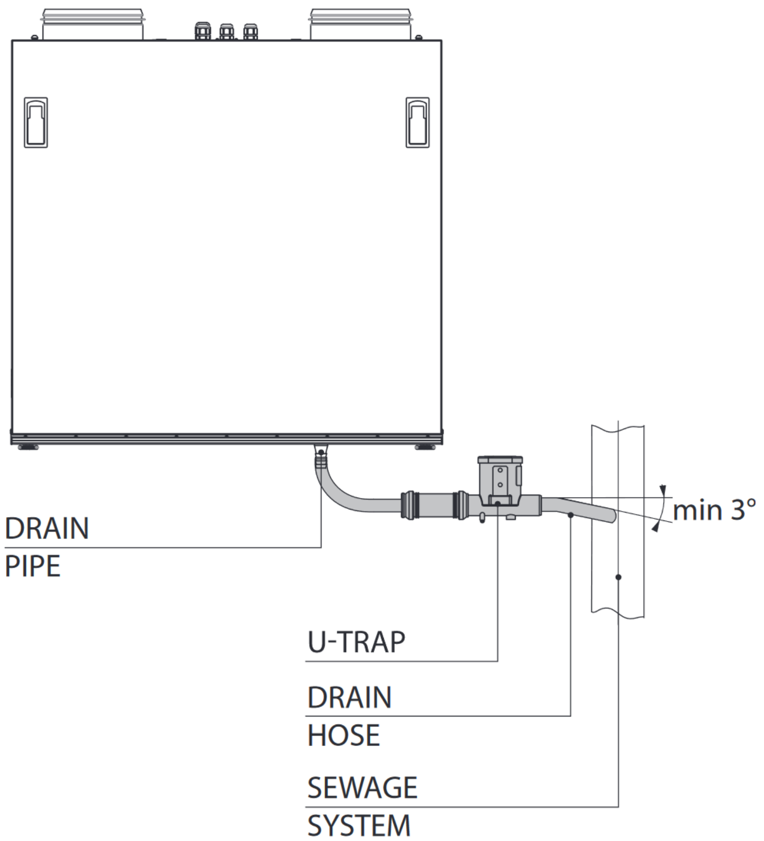


Fig. 2.12. Example of Condensate Drainage Using a Siphon

Drainage pipes are installed along walls in chases with a slope of 2‰ towards the connection to the drainage system. In cases where drainage routes are too long or encounter various obstacles (such as door or window openings, beams, etc.), a drainage pump should be installed (Fig. 2.13). A ***drainage pump*** is a hydraulic machine designed to remove and discharge condensate from equipment in ventilation and air conditioning systems.

Fig. 2.13. Drainage Pump Construction:

1 – Condensate inlet; 2 – Air intake connector for Ø4x6 tube; 3 – Condensate discharge connector; 4, 8 – Connector for Ø 4x6 tube; 5 – Condensate discharge tube connector; 6 – Removable terminal block; 7 – Mounting plate; 9 – Pump holder; 10 – Socket for removable electrical cable

2.6 Filters

A **filter** is a device used to clean air from suspended particles. Filters are classified by purpose and efficiency into general-purpose filters (coarse and fine filters) and filters that meet special air purity requirements, including those for clean rooms (high-efficiency filters and very high-efficiency filters). The European Committee for Standardization (CEN) designates coarse filters with the letter G, fine filters with the letter F, HEPA (High-Efficiency Particulate Air) filters with the letter H, and ULPA (Ultra Low Penetration Air) filters with the letter U.

Each of these four groups is further divided into several classes according to definitions provided in European standards EN 779 and EN 1822 [15]. The filter class indicates the filter's efficiency and is expressed by a specific designation. The first group of filters is divided into 4 classes from G1 to G4, the second into 5 classes from F5 to F9, the third into 5 classes from H10 to H14, and the fourth into 3 classes from U15 to U17. Air filter classification according to various standards, operational characteristics, and application areas are listed in Table 3.5 [15].

Key Characteristics of Filters:

- Nominal Performance (nominal air flow rate): The performance of the filter as defined by the manufacturer.
- Aerodynamic Resistance (pressure drop across the filter): The difference in total pressures before and after the filter at a specified air flow rate.
- Initial Aerodynamic Resistance: The aerodynamic resistance of a clean filter at nominal performance.
- Final Aerodynamic Resistance: The aerodynamic resistance at which the filter should be replaced or regenerated. The final aerodynamic resistance is specified by the manufacturer.
- Dust Holding Capacity: The amount of dust captured and accumulated by the filter until it reaches the final aerodynamic resistance.
- Bypass Factor (Penetration): The percentage ratio of particle concentration after the filter to the particle concentration before the filter.

- Efficiency: Eq. 2.4 is the percentage ratio of the difference in particle concentration before and after the filter to the particle concentration before the filter.

$$\eta = 100 \cdot (q_{\text{п}} - q_{\text{к}})/q_{\text{п}}, \% \qquad (2.4)$$

where $q_{\text{п}}$, $q_{\text{к}}$ are the dust concentrations in the air before and after the filter, respectively, in mg/m^3.

If multiple filters are installed in a ventilation system, their combined efficiency can be determined using the formula:

$$\eta = 100 - (100 - \eta_1) \cdot (100 - \eta_2) \cdot \ldots \cdot (100 - \eta_n), \qquad (2.5)$$

where η_1, η_2, η_n are the efficiencies of the first, second, and n-th filters, respectively, in %.

Standards [16] recommend the following values for final aerodynamic resistance: 250 Pa for coarse filters; 450 Pa for fine filters; 650 Pa for high-efficiency and very high-efficiency filters. European filter manufacturers recommend replacing or cleaning filters when the pressure drop increases two to three times compared to the initial pressure drop.

Standards specify special testing methods for each filter group to determine the filter class and other characteristics at the manufacturing facility. The general classification of air filters is shown in Table 2.3.

Table 2.3

Classification of filters

Type	Class			Cleaning Efficiency (%)				Operational Characteristics (indicates the types of aerosols the filter can capture.)	Usage Recommendation
	DIN 24184 DIN 24185	EN 779	EN 1822	DSTU* 3186-95	EN 779	EN 779	EN 1822		
				A**	A**	E**	O**		
1	2	3	4	5	6	7	8	9	10
Coarse filtration	EU 1	G 1	–	≤60	≤65	–	–	Coarse (>10 μm) dust; welding sparks; cement and fibrous dust; grease vapors; sand	Filter with low air cleanliness requirements
	EU 2	G 2	–	60-70	65-80	<20	–	Fine sand; coal dust; fly ash; textile fibers	For high air pollution, during the operation of compressors and refrigeration units; pre-filtering in HVAC and cooling systems
	EU 4	G 4	–	80-90	90-95	35-45	–	Milk powder; zinc oxide fumes; oil aerosols; mist; fine dust (>5 μm)	
	EU 4	G 4	–	80-90	90-95	35-45	–	Milk powder; zinc oxide fumes; oil aerosols; mist; fine dust	

Продовження табл. 2.3

1	2	3	4	5	6	7	8	9	10
Fine filtration	EU 5	F5	–	90-95	–	45-60	<20	Pigment dust; silica dust; condensation acid dust; alkaline mists	Cycle air cleaning for gas turbine units Second stage filters (polishing) For hospital wards, administrative buildings, hotels, food production, pharmaceuticals, meat and dairy industry
	EU 6	F6	–	95-97	–	60-80	30	Bacteria; natural fog; resin mist; chemical dye aerosols; sanding dust	
	EU 7	F7	–	97-98	–	80-90	45	Wood dust; flying ash; iron oxides; flour dust	
	EU 8	F8	–	98-99	–	90-95	60	Oil mist; ordinary atmospheric dust; agglomerated zinc dust; powder coatings (polymer)	
	EU 9	F9	–	99,8	–	95-98	75	Welding smoke; soldering aerosols; fine atmospheric dust; martensitic furnace fumes	

Продовження табл. 2.3

1	2	3	4	5	6	7	8	9	10
High-Efficiency Particulate Air (HEPA) filters	–	–	H10	–	–	–	85	Sulfur compound smoke; floral pigment; oil smoke; lead oxides; liquid aerosols; radionuclides; tobacco smoke; alkaline mists.	Multi-stage air purification as "final" filters: for addressing issues of sanitation and microclimate in ventilation systems in laboratories, operating rooms, nuclear power plants, fermentation facilities, etc.
	–	–	H11	–	–	–	95		
	–	–	H12	–	–	–	99,5		
	–	–	H13	–	–	–	99,95		
	–	–	H14	–	–	–	99,995		
Ultra Low Penetration Air (ULPA)	–	–	U15	–	–	–	99,9995	Viruses, fumes: all types of airborne dust	Filters for final air cleaning in environments with the highest air purity requirements
	–	–	U16	–	–	–	99,99995		
	–	–	U17	–	–	–	99,999995		

*DSTU - Ukrainian State Standard.

**Testing Methods: A is synthetic (artificial) dust with a median particle size of 5 μm; E is atmospheric dust with a median particle size of 1-3 μm; O is the most penetrating particle or oil mist with a particle size of 0.3.

When designing ventilation systems for public and residential buildings in industrial zones and populated areas near mining industries, it is important to consider the presence of industrial dust in the external air, which requires the use of filters of the appropriate class (according to Table 2.3) in ventilation and air conditioning systems.

For clean rooms, special ***HEPA boxes*** are also used (Fig. 2.14). High-efficiency filtration in such systems occurs directly before the air is delivered to the room, rather than within the installation itself.

Features of this type of filter:

- Uniform distribution of airflow through the filter media.
- Compact design.
- High operational safety.
- Test aerosol inlet for concentration checking.
- Housing for HEPA filters of classes E11 to H14, equipped with a dry (with foamed polyurethane, flat, and U-shaped profiles).

Fig. 2.14. HEPA box

According to their design features, filters are divided into dry (*pocket and cell filters*, Fig. 2.15), electrostatic, ultraviolet, and hydro filters.

Pocket Filter is an air filter with a stationary filter media arranged in the form of deep pockets [1, pp. 13-14].

Cell Filter is an air filter where the filtering element consists of one or more replaceable cells with the filter media fixed in place within a frame [1, p. 14].

Fig. 2.15. Pocket and cell filters

For kitchens, confectioneries, and hot food preparation areas, electrostatic (Fig. 2.16) or ultraviolet (Fig. 2.17) filters are recommended to combat grease, oily vapours, soot, and smoke. Hydro filters (Fig. 2.18) are used in cases where equipment with an open flame, such as ovens and grills, is employed.

An ***Electrostatic Filter*** is an air filter where the functional element is a dielectric filter media placed in an electrostatic field [1, p. 15].

Fig. 2.16. Electrostatic Filter

Operation Principle of Electrostatic Filters: air is drawn in by an external fan through an aluminium mesh pre-filter, which captures large particulate contaminants. The air then passes through the main filter, where a strong electric field is created. In the ionizing section of the filter, particles acquire an electric charge. Charged particles move to the collecting (or collector) section of the filter, which consists of a series of parallel plates. These plates attract and collect particles as small as 0.01 microns. The cleaned air then exits the filter. The heat of the air can be efficiently utilized in heat recovery systems with an intermediate heat transfer fluid.

Ultraviolet Filter (Fig. 2.17) is a module equipped with UV-C+O_3 (Ultraviolet + Ozone) lamps of high power designed to combat grease and odours in the air of ventilation exhaust systems. The frame of such a module is made of stainless steel, and the module's construction is waterproof and resistant to temperatures of 45-50 °C, as well as to fats and oils. It is installed after the coarse filter and grease trap in the duct of local exhaust systems for kitchen equipment (Appendix A).

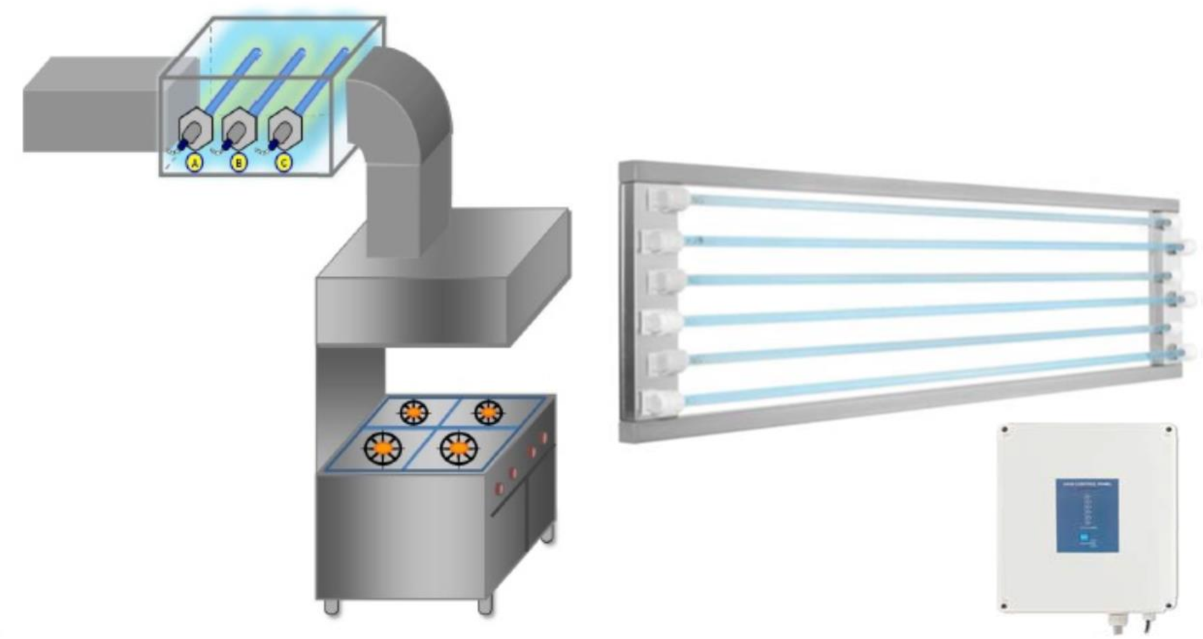


Fig. 2.17. Ultraviolet Filter

In addition to food service establishments, ultraviolet filters are used in medical facilities and laboratories, as ultraviolet radiation performs air disinfection and kills a range of bacteria and viruses.

Hydrofilter is a high-efficiency water-based filter with a closed-loop cooling water circulation system in a high-pressure circuit (Fig. 2.18), which performs spark extinguishing, cooling, and cleaning of the air from flames, soot, tar, grease, odours, and smoke. The main task of the hydrofilter is to effectively prevent ignition and subsequent fires in the exhaust duct systems of food service establishments and to reduce excessive smoke, soiling, and grease buildup on duct walls. Wet air cleaning and cooling are carried out using a water curtain, while mechanical cleaning occurs within the filters (Fig. 2.19). Explanation in Fig. 2.19:

1. **Suction Pipe of the Pump**: The pipe through which air is drawn into the hydrofilter.
2. **Discharge Pipe**: The pipe through which cleaned air is expelled from the hydrofilter.
3. **System Filling Valve with Float Mechanism**: A valve used to fill the system with water, equipped with a float to maintain the correct water level.
4. **Emergency Cooling Supply Valve**: A valve used to provide additional water for cooling in case of an emergency.
5. **Connection Valve for External Water Supply**: A valve for connecting the hydrofilter to an external water supply.
6. **Cooling Solenoid Valve**: A solenoid-operated valve that controls the flow of cooling water.
7. **Upper Overflow**: An outlet that prevents the system from overfilling by allowing excess water to escape.
8. **Lower Drain**: A drain for removing accumulated water from the system.
9. **Visual Level Indicator**: A gauge or indicator used to monitor the water level within the system.
10. **Flush Valve**: A valve used for flushing the system with water to clean out contaminants.
11. **Automation Control Panel**: The panel housing the controls and sensors for automating the operation of the hydrofilter.
12. **Drain Valve without Foam Cleaning Agent**: A valve for draining the system without using foam cleaning agents.

Fig. 2.18. Hydrofilter «SIGOV» [17]

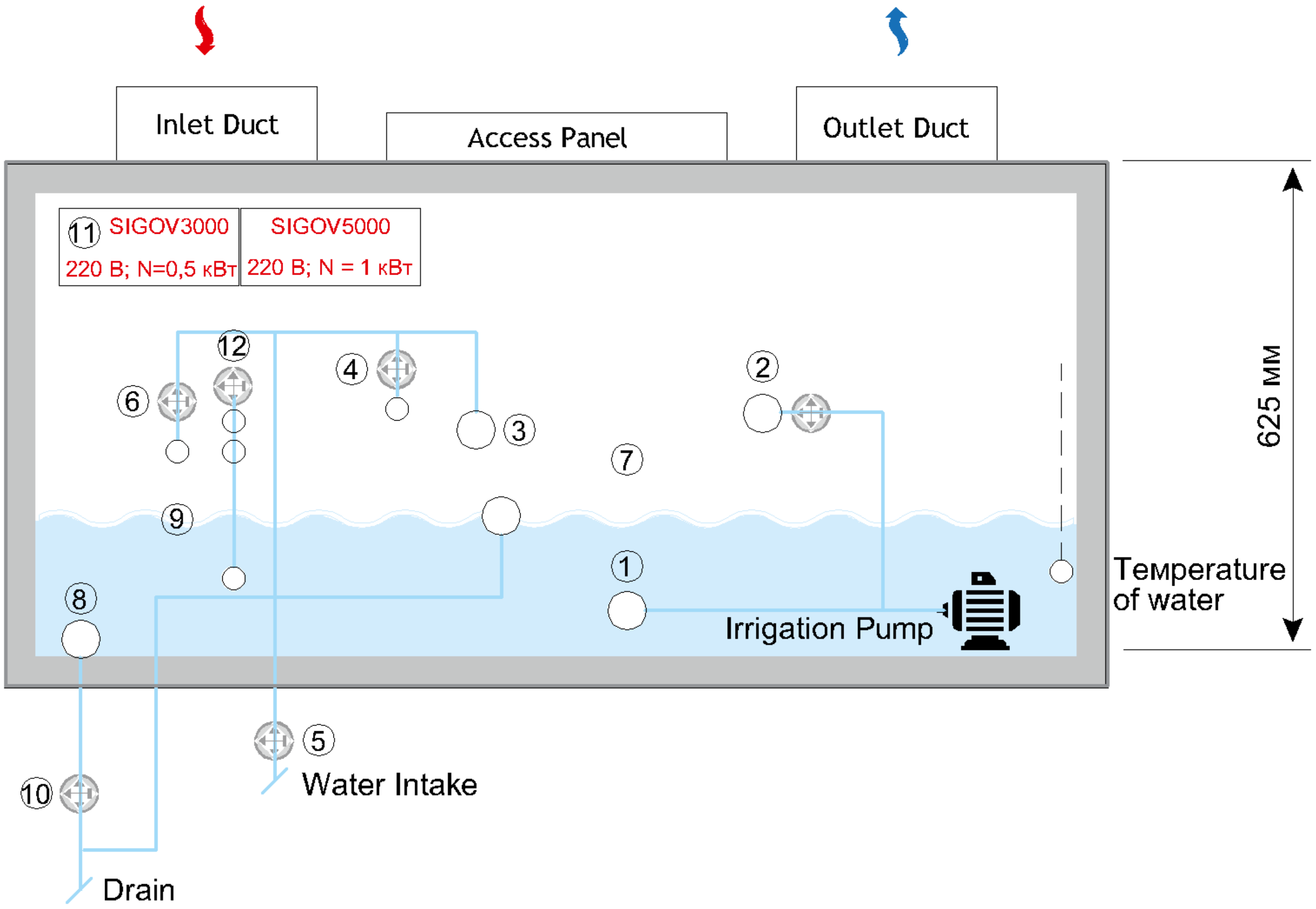


Fig. 2.19. Schematic Diagram of the Hydrofilter Operation «SIGOV» [17]

2.7 Valves

1. **Air Valve** is a device used to regulate the airflow (Fig. 2.20, Fig. 2.21). They come in manual and automatic regulation types. Automatic airflow control is achieved by installing electric actuators (Fig. 2.22).

1.1. **Air Damper** is a device that changes the cross-sectional area and regulates the airflow passing through it (Fig. 2.20). Dampers can be rotary or sliding perpendicular to the airflow [1, p. 23].

1.2. **Throttle Valve** is a device used to shut off or restrict airflow in a duct, featuring a rotary element matching the duct's cross-section (Fig. 2.21) [1, p. 23].

2. **Check Valve** is a valve designed to close off airflow in round and rectangular ducts and prevent the reverse movement of air when the fan is turned off (Fig. 2.23). The valve plate opens under the pressure created by the airflow.

Fig. 2.20. Air Damper

Fig. 2.21. Throttle Valve

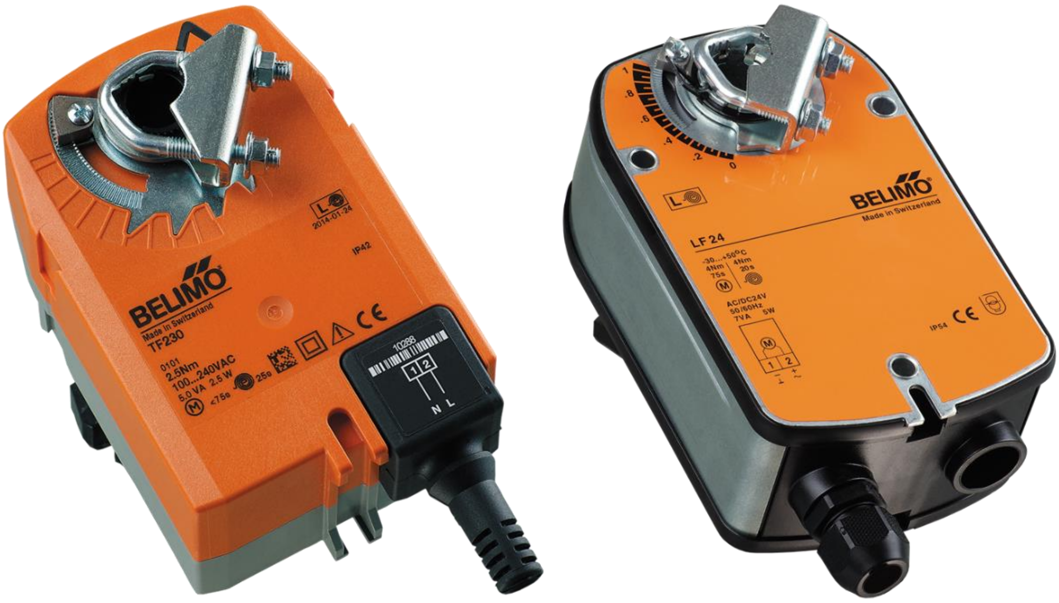


Fig. 2.22. Air Damper Actuators

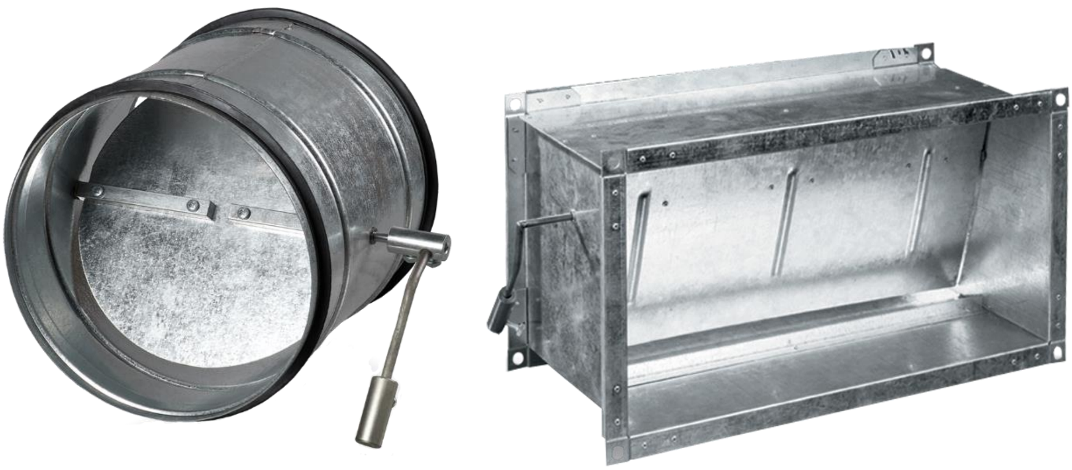


Fig. 2.23. 2. Check Valve

2.8 Flexible Duct Connectors

Flexible duct connectors are designed to prevent the transmission of vibrations from fans or ventilation units to the ductwork, as well as to partially compensate for thermal expansion in the duct system. They consist of two flanges connected by a vibration-absorbing material. Flexible connectors come in circular and rectangular cross-sections (Fig. 2.24).

Fig. 2.24. Rectangular and Circular Flexible Connectors

2.9 Ductwork Network

Ducts can be circular or rectangular in cross-section and made of plastic or metal. The ductwork network consists of straight duct sections and fittings (Fig. 2.25). It is recommended to assemble the ductwork network using standardized parts and branch fittings.

Circular Ducts

A ***circular duct*** is the optimal shape for ductwork, offering the smallest perimeter for a given cross-sectional area. This results in minimal aerodynamic resistance to the airflow and, consequently, lower noise levels. Circular ducts are particularly advantageous for creating extended ventilation routes. They are widely used in residential, commercial, and industrial applications for installing air distribution systems in ventilation networks.

Types of circular ducts include *straight-seam and spiral-wound.*

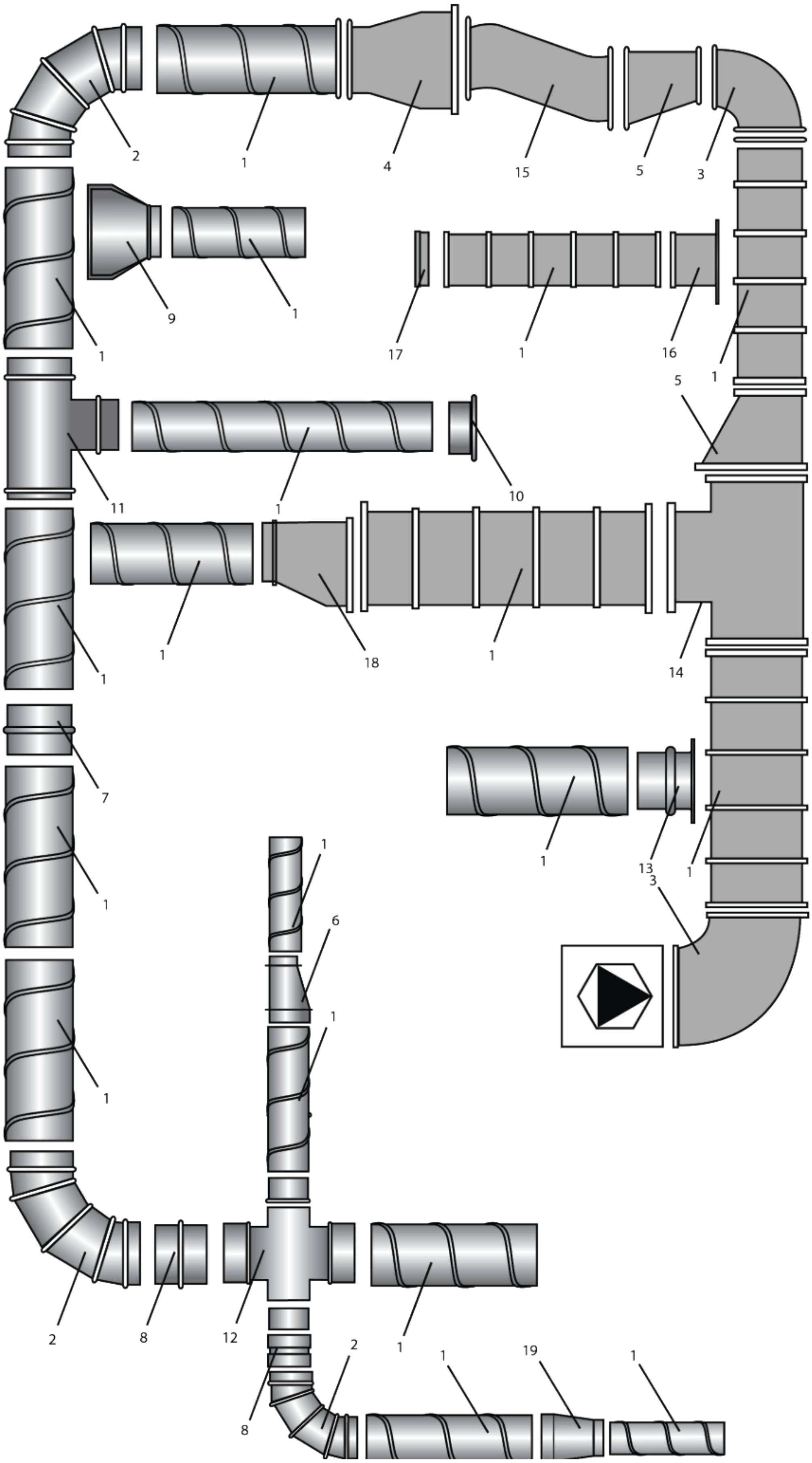


Fig. 2.25. Ductwork Installation Diagram

Explanation of elements in Fig. 2.25:

1. Straight Sections (Circular and Rectangular Cross-Sections);
2. 90° Circular Duct Elbow;
3. 90° Rectangular Duct Elbow;
4. The transition from Rectangular to Circular Duct;
5. The transition from Rectangular to One-Sided Rectangular Duct;
6. The transition from Circular to One-Sided Circular Duct;
7. Internal Nipple;
8. Coupling;
9. Branch Saddle;
10. End Cap;
11. Circular Tee;
12. Cross;
13. Circular Duct Branch;
14. Rectangular Duct Tee;
15. Rectangular Duct Takeoff;
16. Branch;
17. Rectangular End Cap;
18. The transition from Rectangular to Circular Duct;
19. Central Transition from Circular to Circular Duct.

Table 2.4

Standard Sizes for Circular Ducts

Standard Duct Diameter	Metal Thickness
100 mm (4 in)	0,5 mm
125 mm (5 in)	
150 or 160 mm (6 in)	
200 mm (8 in)	
250 mm (10 in)	0,6 mm
280 mm (11 in)	
315 mm (12 in)	
355 mm (14 in)	
400 mm (16 in)	

<table>
<tr><td>450 mm (18 in)</td><td></td></tr>
<tr><td>500 mm (20 in)</td><td rowspan="6">0,7 mm</td></tr>
<tr><td>560 mm (22 in)</td></tr>
<tr><td>630 mm (25 in)</td></tr>
<tr><td>710 mm (28 in)</td></tr>
<tr><td>800 mm (32 in)</td></tr>
<tr><td>900 mm (36 in)</td><td rowspan="3">1,0 mm</td></tr>
<tr><td>1000 mm (40 in)</td></tr>
<tr><td>1250 mm (50 in)</td></tr>
<tr><td>1400 mm (56 in)</td><td rowspan="2">1,2 mm</td></tr>
<tr><td>1600 mm (64 in)</td></tr>
</table>

Advantages:

- *Good Sealing:* Circular ducts offer excellent air-tightness.
- *High Strength:* They maintain shape under external loads and pressure changes effectively.
- *Energy Efficiency:* Lower pressure losses in the ventilation system contribute to energy savings.
- *Reduced Fastening Requirements:* Requires less material for sealing and fewer supports.
- *Lightweight and Compact:* Can be installed by two workers, making handling and installation easier.
- *Long Lifespan:* Durable and reliable over extended periods.
- *Material Cost Savings:* Smaller size and perimeter of circular ducts reduce the need for thermal and fire insulation materials.

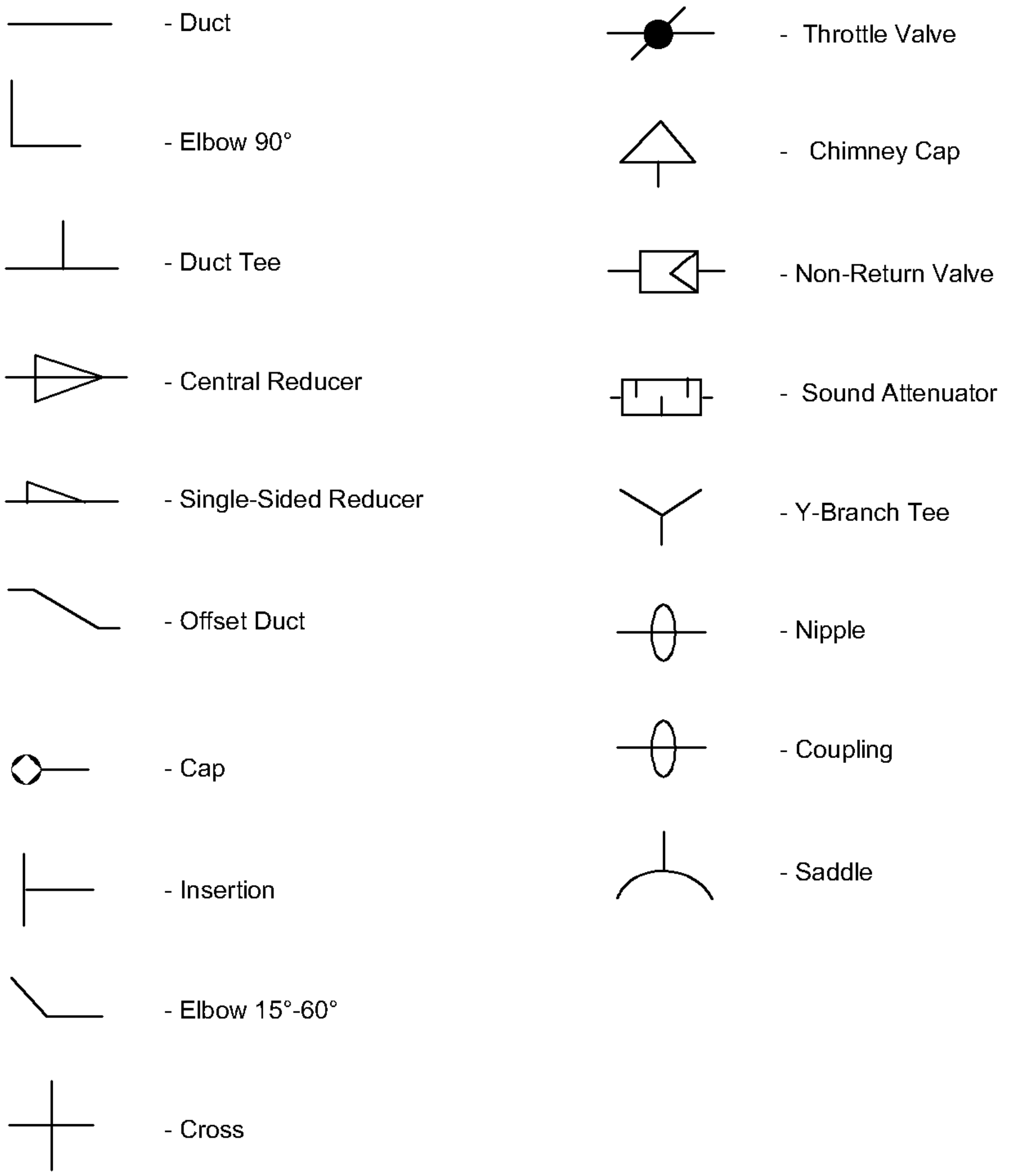


Fig. 2.26. Conventional Symbols for Round Duct Elements

Rectangular Ducts

Rectangular Cross-Section is optimal for installations with limited height or width constraints. They are easily installed in confined spaces or suspended ceilings with minimal depth, which helps preserve the maximum possible height of the room or allows for ducting in narrow shafts.

Table 2.5

Standard Sizes for Rectangular Ducts

Standard Duct Diameter, mm	Metal Thickness
100x100, 150x100, 150x150, 200x100, 200x150, 200x200, 250x100, 250x150, 250x200, 250x250	0,5 mm
300x100, 300x150, 300x200, 300x250, 300x300, 350x150, 350x200, 350x250, 350x300, 350x350, 400x150, 400x200, 400x250, 400x300, 400x350, 400x400, 450x150, 450x200, 450x250, 450x300, 450x350, 450x400, 450x450, 500x200, 500x250, 500x300, 500x350, 500x400, 500x450, 500x500, 550x200, 550x250, 550x300, 550x350, 550x400, 550x450, 550x500, 550x550, 600x200, 600x250, 600x300, 600x350, 600x400, 600x450, 600x500, 600x550, 600x600, 650x250, 650x300, 650x350, 650x400, 650x450, 650x500, 650x550, 650x600, 650x650, 700x250, 700x300, 700x350, 700x400, 700x450, 700x500, 700x550, 700x600, 700x650, 700x700, 800x300, 800x350, 800x400, 800x450, 800x500, 800x550, 800x600, 800x650, 800x700, 800x750, 800x800, 850x300, 850x350, 850x400, 850x450, 850x500, 850x550, 850x600, 850x650, 850x700, 850x750, 850x800, 850x850, 900x300, 900x350, 900x400, 900x450, 900x500, 900x550, 900x600, 900x650, 900x700, 900x750, 900x800, 900x850, 900x900, 1000x350, 1000x400, 1000x450, 1000x500, 1000x550, 1000x600, 1000x650, 1000x700, 1000x750, 1000x800, 1000x850, 1000x900, 1000x950, 1000x1000	0,7 mm
Larger Dimension from 1250 mm to 2000 mm	0,9 mm

Applications:

- Public buildings
- Industrial buildings
- Residential spaces

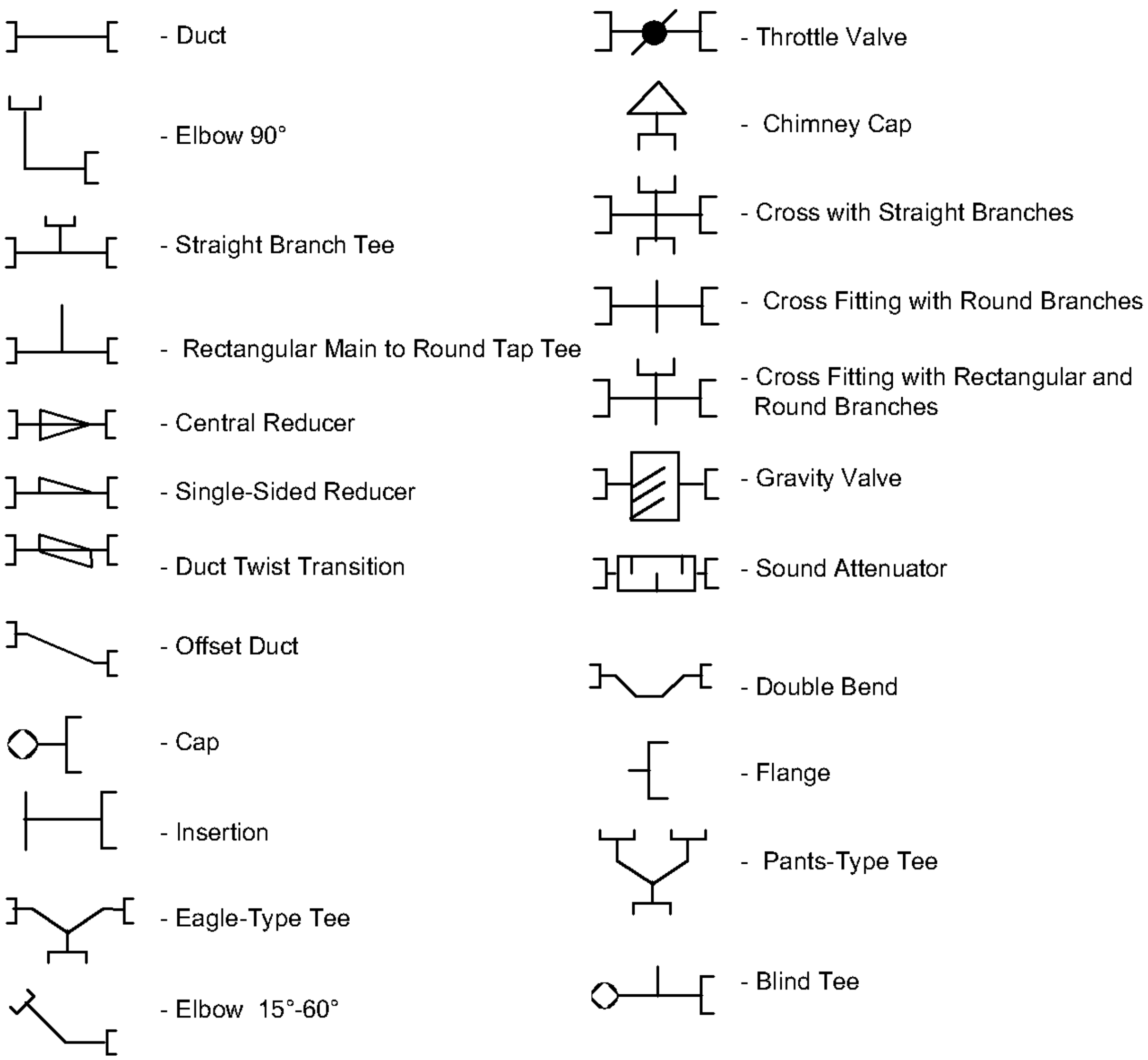
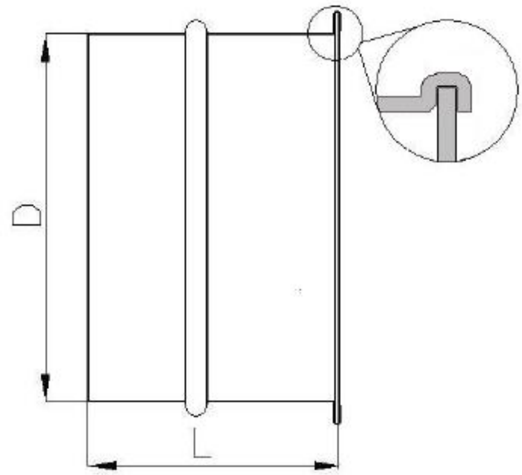


Fig. 2.27. Symbols for Rectangular Duct Elements

Caps

Caps are used to seal the end of a duct branch to prevent air leakage and to block air from entering. They are also installed temporarily if duct installation is incomplete, providing protection against unwanted elements and dust. Thus, caps enhance the operational safety of ventilation systems and prevent contamination of ducts that have not yet been fully installed.

Caps can be installed on both internal and external ducts that pass through the building facade.



Caps, D	Length, L
up to 630 mm	100 mm
over 630 mm	150 mm

Fig. 2.28. Round Duct Cap

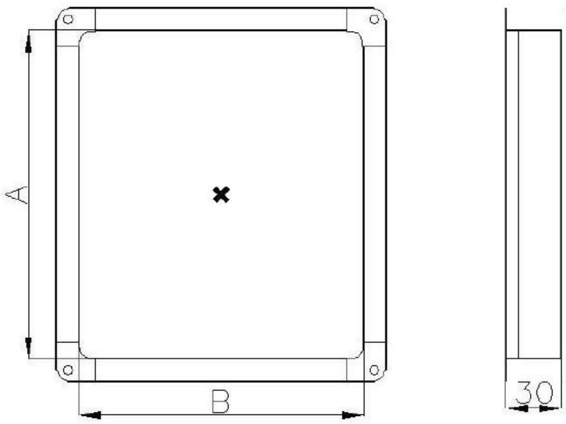


Fig. 2.29. Rectangular Duct Cap

Insertion

An ***insertion*** is similar to a tee fitting, but unlike the latter, it occupies less space and has a lower metal content. There are two types of insertions: straight (Fig. 40, Fig. 41) and saddle (Fig. 42).

A ***saddle insertion*** is used to connect a round duct to another round duct. Saddle insertions are used in ventilation systems and are installed in production, warehouse, or office environments.

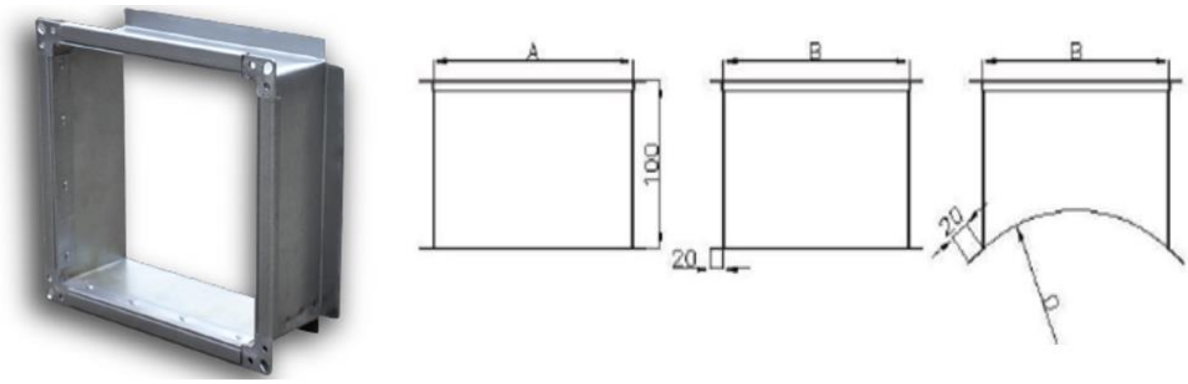
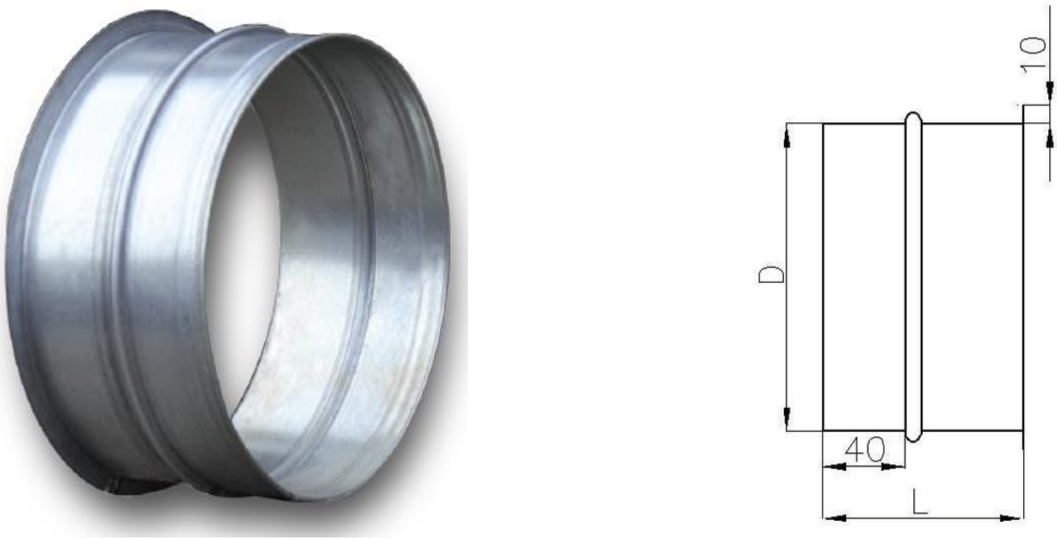


Fig. 2.30. Straight Insertion for Rectangular Ducts



Insertion, D	Length, L
up to 630 mm	100 mm
over 630 mm	150 mm

Fig. 2.31. Straight Insertion for Circular Ducts

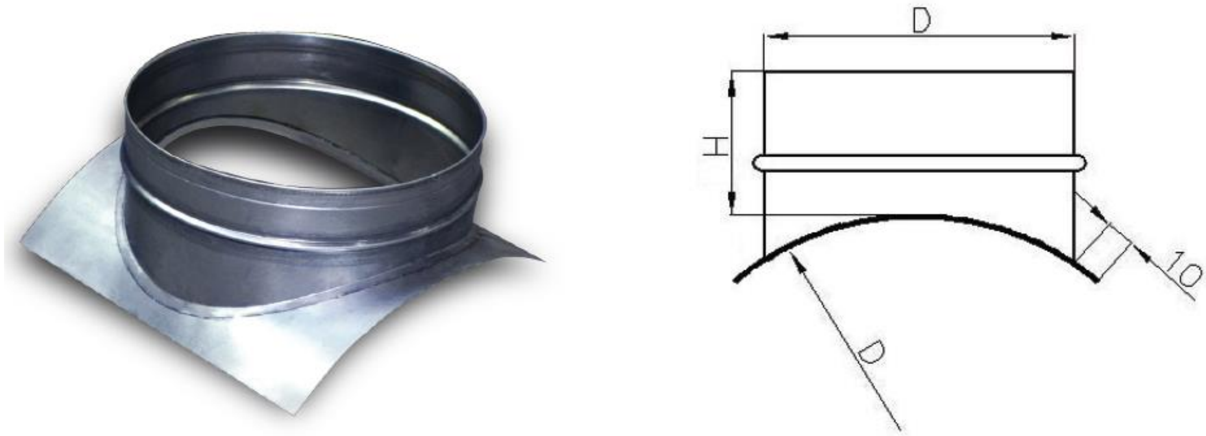


Fig. 2.32. Circular Duct Saddle Insertion

Duct Tee

A ***tee*** is designed to branch a single airflow duct line into two or to combine two airflows into one.

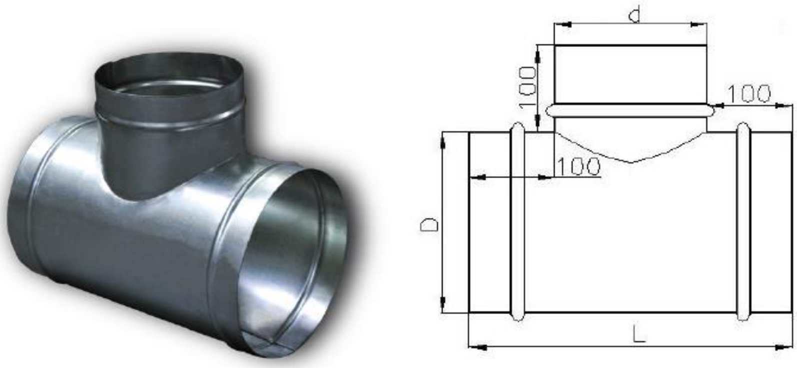


Fig. 2.33. Straight Tee with Round Cross-Section

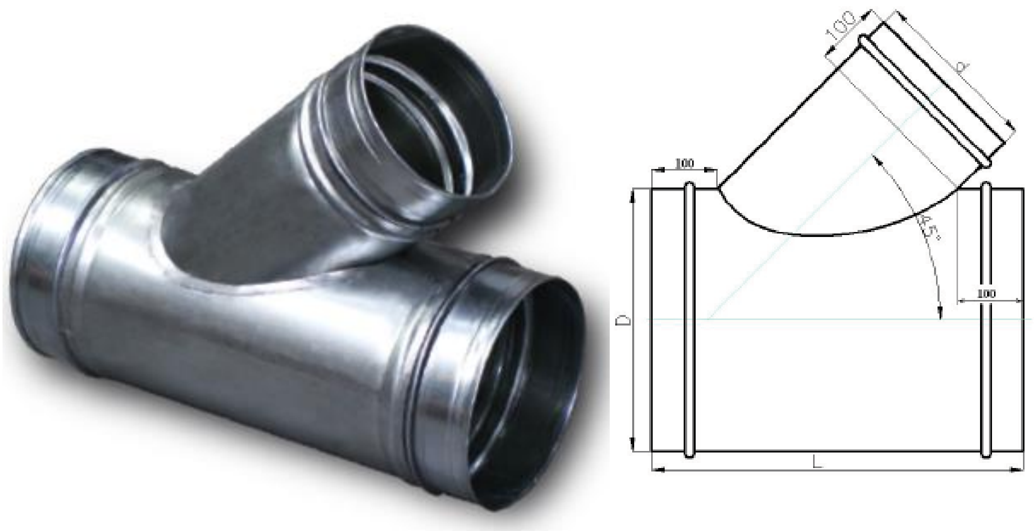


Fig. 2.34. 45° Elbow Tee

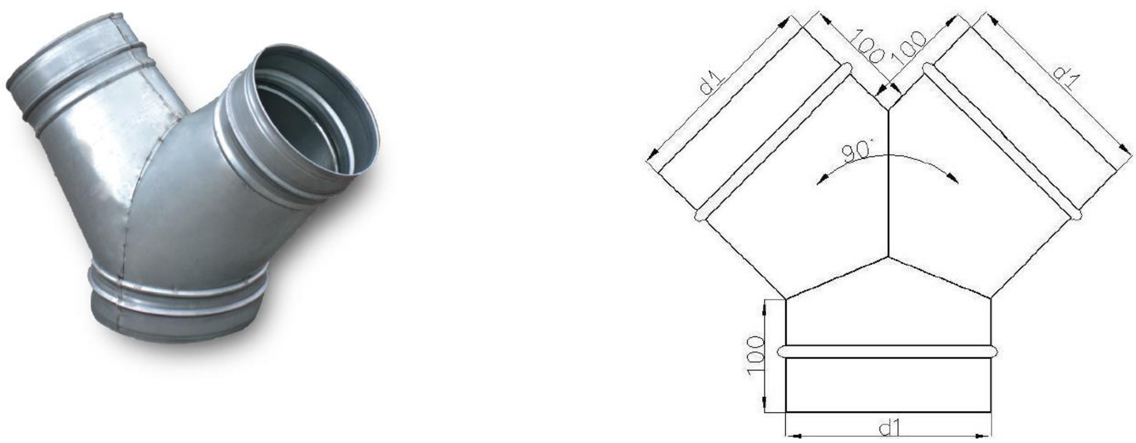


Fig. 2.35. Y-Branch Tee with Equal Diameter Offshoots

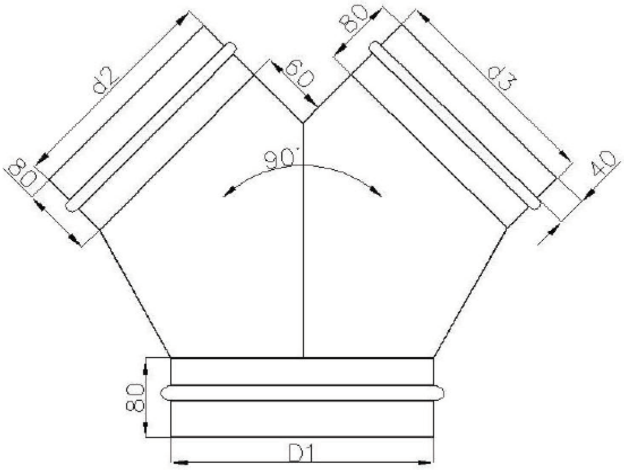


Fig. 2.36. Y-Branch Tee with Different Diameter Offshoots

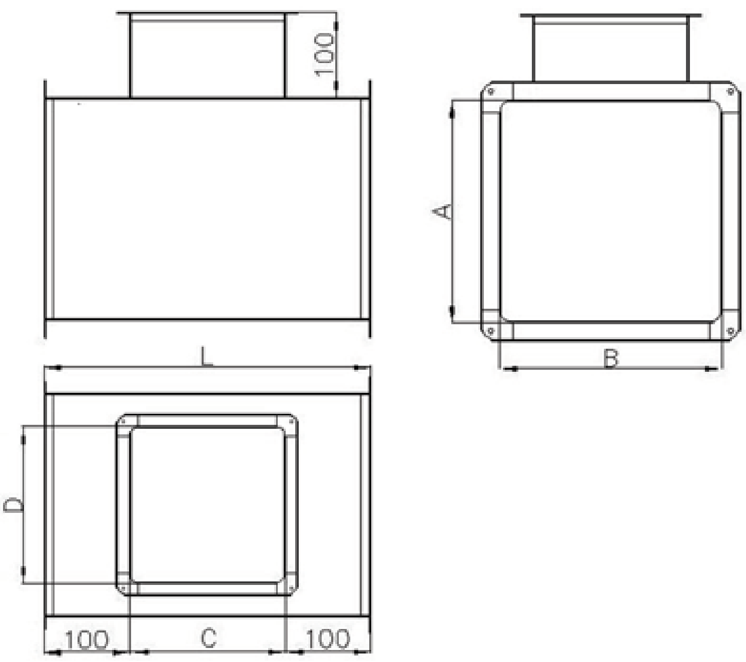


Fig. 2.37. Straight Rectangular Tee

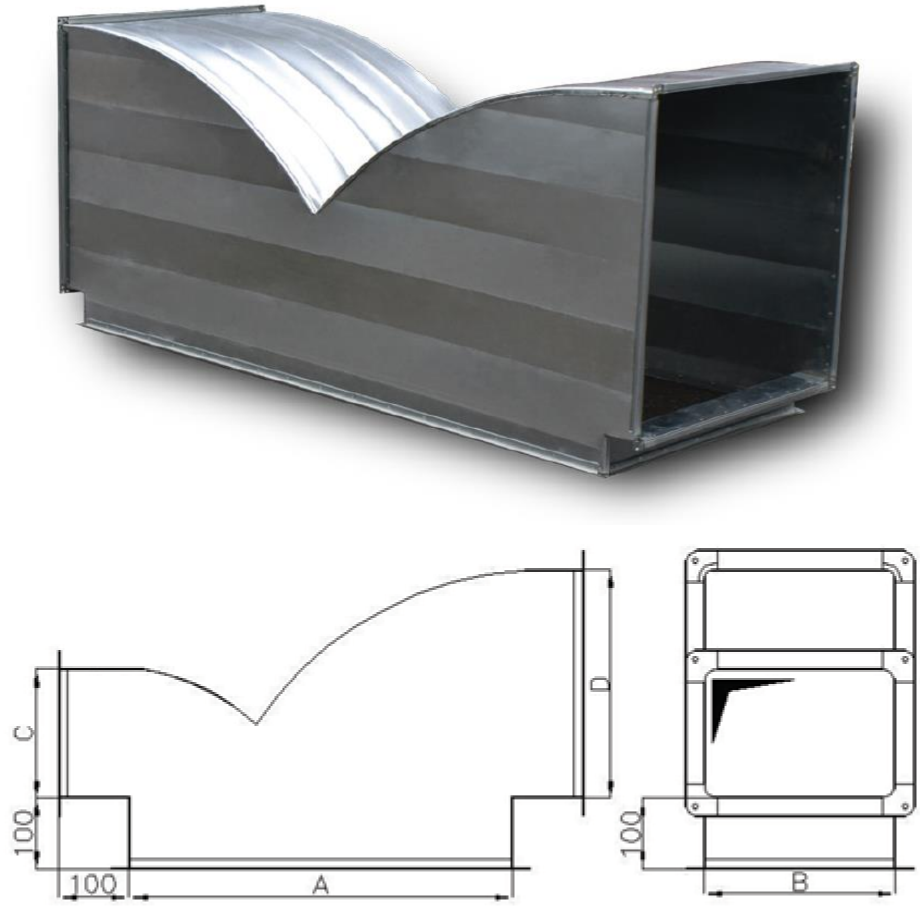


Fig. 2.38. Eagle-Type Tee

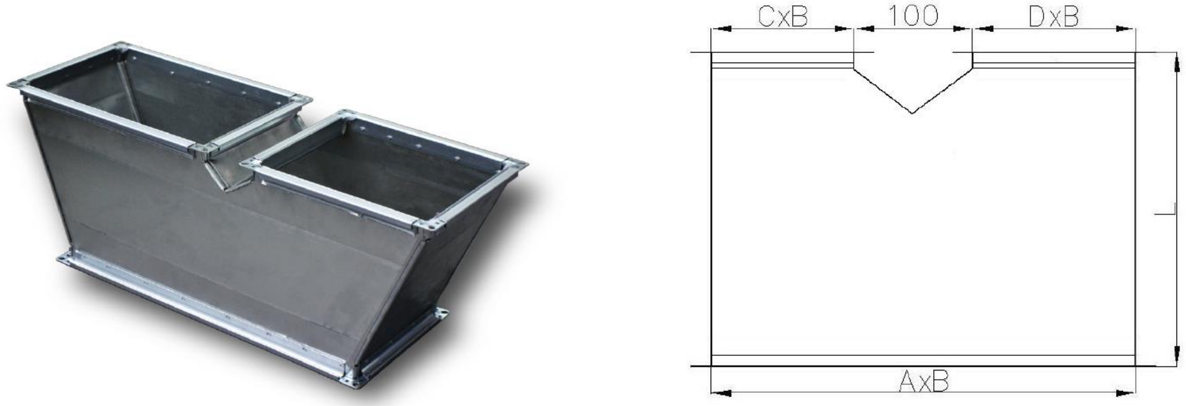


Fig. 2.39. Pants-Type Tee

Cross

Cross is a fitting used for branching airflow into three directions or for combining three branches of a ventilation system.

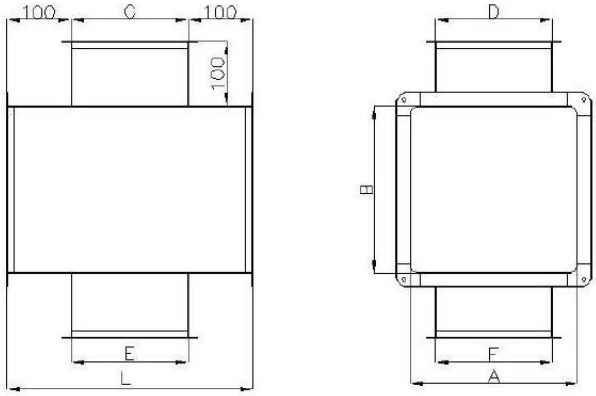


Fig. 2.40. Straight Rectangular Cross

Elbows 90°, 45°, 30°

A ***segmented elbow*** for round ducting is designed to smoothly redirect the airflow.

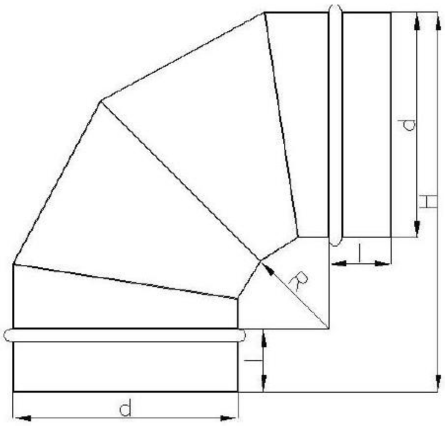


Fig. 2.41. Segmented 90° Elbow for Round Duct

Diameter d, mm	R, mm	H, mm	L, mm
100	65	205	40
125	100	275	50
150	110	310	50
160	115	325	50
200	120	370	50
250	130	430	50
280	140	470	50

315	160	525	50
355	180	585	50
400	190	640	50
450	200	700	50
500	210	760	50
560	220	830	50
630	230	910	50
710	250	1030	70
800	260	1130	70
900	280	1250	70
1000	290	1360	70
1100	320	1490	70
1250	380	1700	70

Fig. 2.42. Segmented Elbow 60°, 45° Circular Section

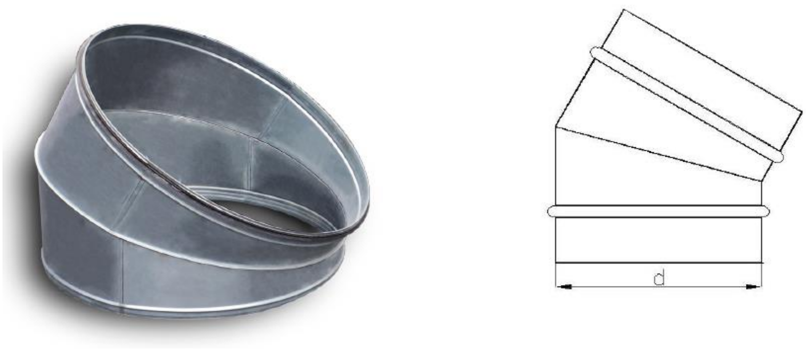


Fig. 2.43. Segmented Elbow 30°, 15° Circular Section

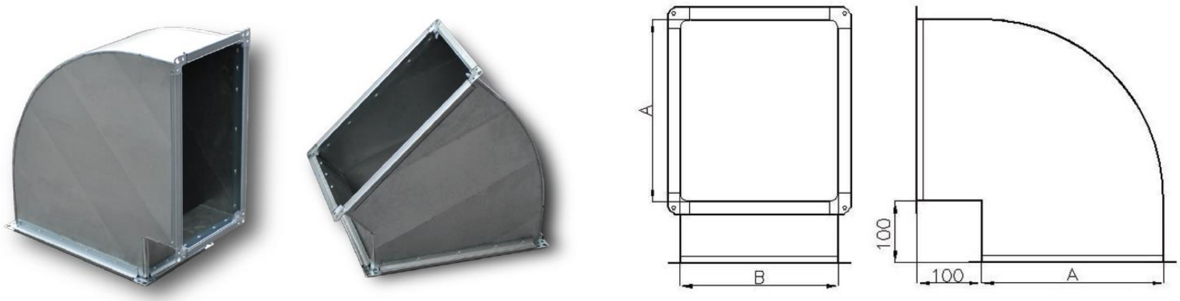


Fig. 2.44. 90° Elbow Rectangular Section

Elbow 60°, 45°		Elbow 30°, 15°	
Diameter d, mm	R, мм	Diameter d, mm	R, мм
100	70	100	70
125	130	125	100
150	150	150	100
160	160	160	100
200	190	200	100
250	220	250	100
280	230	280	100
315	250	315	100
355	260	355	100
400	280	400	100
450	290	450	100
500	300	500	100
560	305	560	100
630	310	630	100
710	335	710	150
800	350	800	150
900	360	900	150
1000	380	1000	150
1100	380	1100	150
1250	380	1250	150

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APPENDIX A
EXAMPLE OF INSTALLATION OF LOCAL EXHAUST SYSTEM WITH UV FILTERS

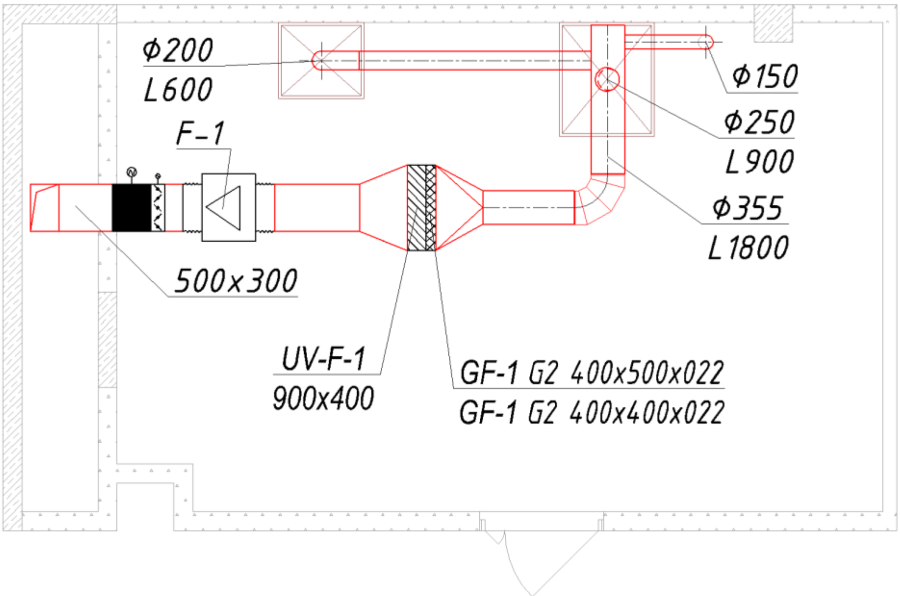

Fig. A1. Floor Plan Fragment.
Local Exhaust System with UV Filters

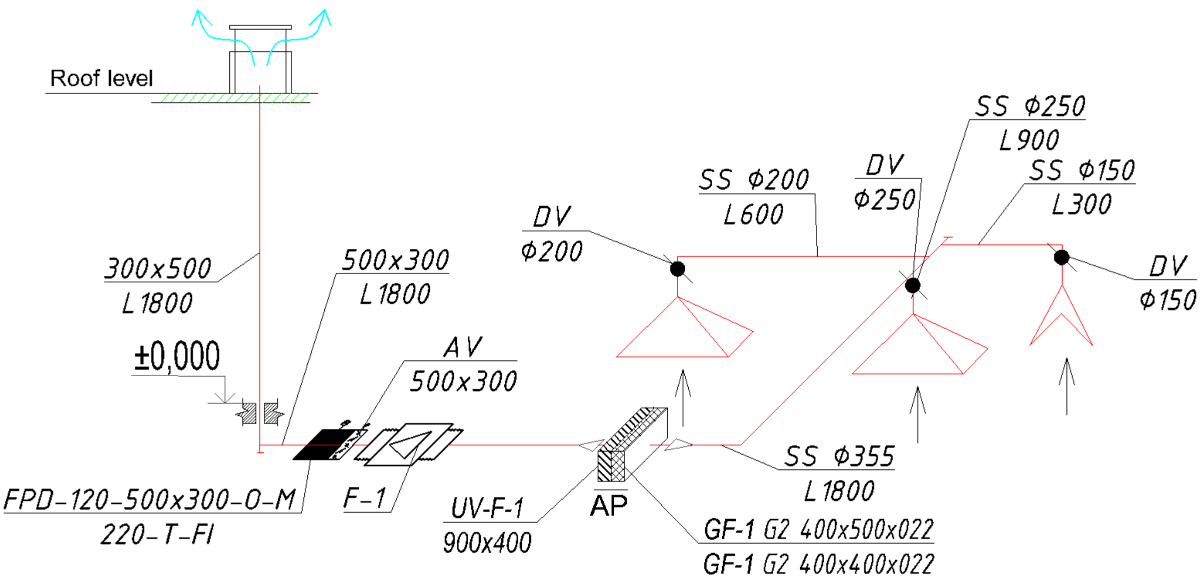

Fig. A2. Axonometric Diagram of the Local Exhaust System
with UV Filters

Educational and Methodological Publication

VENTILATION EQUIPMENT FOR RESIDENTIAL AND PUBLIC BUILDINGS

Methodological Guidelines
for Practical Classes, Course Design, and Final Certification Works for Students of Specialty
G19 "Construction and Civil Engineering"

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