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Collective protection measures - methods to ensure clean air

Władysław HARMATA*[1], Zbigniew SZCZEŚNIAK[2], Marian SOBIECH[2], Adam BARYŁKA[2]

[1] *Faculty of Advanced Technologies and Chemistry, Military University of Technology, Warsaw, Poland*
[2] *Faculty of Civil Engineering and Geodesy, Military University of Technology, Warsaw, Poland*

Abstract

The review article deals with the current issue of collective protection, including collective protection against contamination. The division of collective protection means by purpose and basic equipment for use under conditions of contamination is presented. Based on NATO documents, functional and operational recommendations were formulated. Methods of protecting facilities from the penetration of contaminated air by sealing, dilution in vestibules and the creation of positive pressure support were characterized. Methods of ventilating facilities with respect to changing the composition and properties of air in confined spaces are presented, including determining the necessary amount of air to ventilate rooms to remove excess CO2, water vapor, heat and oxygen deficiency. Methods of supplying clean air to the facility by means of air filtration and regeneration are characterized.

Keywords: protection against contamination, collective protection, crisis management.

1 Introduction

In the armed forces and in the National Fire Service, individual protective equipment (IPE) are the basic equipment for operating under contamination hazards. It is important to realize that most tasks can be performed in the assumed IPE, but they have a limited time of use and adversely affect users. To reduce these inconveniences, collective protection systems (CPS) are used, which provide protection of life and health in the event of extraordinary threats (natural disasters, under conditions of war with or use of weapons of mass destruction). Publication Szkol. 978/2020 defines collective protection against contamination as an activity that ... "aims to increase the ability of troops to survive while continuing operations in contaminated terrain, as well as to provide them with rest. The use of CPS helps to reduce the psychological and physiological effects of operating in contaminated terrain, which are produced during prolonged stay in IPE." [1].

The following types of CPS are distinguished [2,3,4]:

1. Fixed (stationary) collective protection facilities against contamination. These are collective protection facilities not intended to be moved, with which units are equipped in places of permanent dislocation (such as airports, command and control facilities and command facilities, hospitals, material bases). They should be at the disposal of units that must carry out their tasks continuously, even when they find themselves in the area of contamination. They must have enhanced protective characteristics against conventional attacks and

* **Corresponding author:** E-mail address: (wladyslaw.harmata@wat.edu.pl) Władysław HARMATA

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WMD strikes. They are divided into heavy, medium and light types. Heavy and medium type facilities provide protection not only against WMD, but also against conventional rockets and bombs, light type facilities do not guarantee such protection and their main purpose is to protect people from WMD grosses. In the US Army, fixed CPSs are divided into active and passive systems. Active systems use high-efficiency filtering systems and rugged buildings or shelters. These systems provide the highest level of protection over a long period of time. Passive systems use buildings or shelters as a protective barrier, limiting the exchange of outside air. Protection is better the less outside air enters.

2. Mobile collective means of protection against contamination. This group includes land vehicles (tanks, combat vehicles and others), aircraft and ships, equipped with sealing devices designed to prevent internal contamination and having air filtration systems. These systems should allow for use on the move and at a standstill. Based on the degree of protection provided and the way they are integrated into the base platform, they are divided into:
   - respiratory support (in masks) - installed in vehicles, or aircraft, to provide the crew with better filtration and higher air output. These systems are used in cases where it is not possible (or expedient) to provide positive pressure and filtration throughout the vehicle (aircraft) space when it is necessary to provide greater air output to personnel (crew) using individual respiratory protection equipment. They supply purified air to the mask filtering devices, which reduces breathing resistance in the mask, in addition in cold conditions the supplied air can be heated,
   - positive pressure - a positive pressure is created inside the system, which prevents contaminated air from getting inside,
   - hybrid - are a combination of respiratory support systems and positive pressure, which can operate simultaneously or separately,
   - full (complete) - these are positive pressure or hybrid systems, equipped with air conditioning. Cooling the air supplied to the interior reduces heat stress on working personnel.
3. Transportable collective means of protection against contamination (adapted for transport - container and tent) are protective systems that can be set up and rolled up, and then transported as needed as a stand-alone, independent of installations in buildings. They can also include wheeled or tracked vehicles.

Among the collective protection systems that use positive internal air pressure to provide security, we can distinguish three categories:

1. Having a controlled contamination zone and a lock. Under contamination conditions, they allow frequent entry and exit of the facility without causing contamination of the facility and with collective protection requirements. These systems allow personnel working in them to enter and leave the facility at any time, regardless of the prevailing contamination conditions. These facilities must be equipped in such a way that the mask and protective clothing can be removed inside. Examples of such facilities include combat operations centers, commands, hospitals.
2. Equipped with a lock, but without a controlled contamination zone. In facilities of this type, personnel who have not been contaminated with liquid CW agents may enter and leave the facility only when the level of contamination is low. Personnel contaminated with liquid CWs may not enter the facility so as not to create the danger of transferring contamination to the uncontaminated zone. The uncontaminated zone must be equipped with equipment to monitor the level of contamination in order to control whether there is an accumulation of toxicant vapors to a dangerous level. These systems allow limited ingress and egress. Examples of such systems include some ships, simplified shelter systems and some vehicle-mounted container systems.
3. Systems that do not have a lock or controlled contamination zone. Facilities equipped with such systems provide protection against contamination if hatches and doors remain closed. By entering or leaving the facility, the protective properties of the facility are lost. Examples of such facilities include tanks and combat vehicles.

The use of collective protection systems stems from the need to remain in an area where there is a high risk of WMD use or to operate for a long time in a contaminated area. It is always necessary to assess whether the opponent has the means to execute a strike on the area and whether the own forces have the ability to protect themselves through maneuver.

2 Functional and operational recommendations for collective protective equipment

The equipment of the armed forces with collective protection systems against contamination depends on the nature of the operational tasks they carry out and the level of threat of enemy use of WMD. Collective protection systems, depending on their intended use, may include the following modules [5]:

- filtering device[1)] - cleans the air of contaminants, maintains positive pressure inside the system, allows cleaning of air locks,
- air conditioning module - maintains the required temperature and humidity,
- oxygen regeneration module - serves to replenish oxygen deficiency in the atmosphere, if necessary,
- air recirculation filter - filtering device, operating in the uncontaminated zone, provides additional protection against the accumulation of low concentrations of contaminants inside the CPS,
- power supply module - providing power to the devices that ensure the functioning of the system. Power can be drawn from the mains, a generator or from the carrier platform (in mobile systems),
- uncontaminated zone (TFA) [2)] - In this zone, personnel can stay without wearing IPE. It should provide an airtight seal to create adequate positive pressure. It can be divided into several rooms. Air flow should take place in it in such a way as to prevent areas with obstructed air exchange. It can be equipped with devices for monitoring contamination, pressure, filter wear, lighting and others as required,
- airlock[3]) - creates a room between the uncontaminated zone and the controlled contamination zone, purified with air from the uncontaminated zone. This prevents TFA contamination during entry and exit,
- controlled contamination area (CCA)[4)] - should be located in front of the airlock. The design and equipment depend on the intended use, the anticipated threat, the number of people using the system, and the expected volume of traffic. The SKS may include the following elements:
  - control zone - designed to control entry and exit, preliminary procedures such as personnel identification,
  - checkpoint - equipped with detectors to control contamination of personnel and equipment,
  - danger zone of liquid poisonous agents (LHA)[5)] - is entered directly from outside, special procedures are performed in it, personnel remove and store equipment in it,
  - changing room[6)] -should be located behind the LHA, contaminated protective clothing (or overlays) is removed here in relatively safe conditions, provided by strong airflow from the uncontaminated zone,

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[1] air filtration unit - in collective protection against contamination, a device that provides clean air to the uncontaminated zone. [NO-01-A006, AAP-21]

[2] toxic free are - in collective protection against contamination, a contamination-free space that is sealed. There is positive pressure in it and clean air is supplied, which allows the state of individuals to stay in it without the need for individual contamination protection measures. [NO-01-A006, AAP-21].

[3] airlock - in collective protection against contamination, a room located between an uncontaminated zone and a zone of controlled contamination or a source of nuclear, biological and chemical danger, having a double door into which clean air is supplied, creating the possibility for a state of persons to move from one zone to another and at the same time preventing the penetration of contamination into the uncontaminated zone. [NO-01-A006, AAP-21].

[4] contamination control area - in collective protection against contamination, the zone located in front of the uncontaminated zone, in which the state of personnel can remove contaminated individual protective equipment against contamination in order to reduce the risk and in which decontamination of equipment and materials can be carried out; the zone includes airlocks, zones threatened by vapors of toxic warfare agents, changing rooms, and zones threatened by liquid poisonous agents. [NO-01-A006, AAP-21].

[5] liquid hazard area - in collective protection against contamination, that part of the zone of controlled contamination, which is located immediately behind the entrance from the contaminated area and in which the personnel state can carry out the elimination of contamination. [NO-01-A006, AAP-21].

[6] changing booth - in collective protection against contamination, a room inside a controlled contamination zone into which purified air is pumped and where people can safely remove or put on protective clothing. [NO-01-A006, AAP-21].

- particulate hazard area[7] - dusts are removed in this zone, for example, through the use of showers,
- vapour hazard area [8] - should be located directly in front of the airlock, masks can be changed here, or other IPE items not previously removed, in this zone there should be a strong supply from the uncontaminated zone,
- storage zones - may be used in conjunction with other zones to store clean, contaminated or spare equipment,
- waste storage zones - can be used in conjunction with other zones to store clean or contaminated waste [6,7].

Recommendations currently under development [4,5] stipulate that collective protection systems for the Combined Forces, depending on their purpose, should have specific modules.

Related to the recommended SOZ equipment is their division into four levels (Table 1).

Table 1. Recommended completion of collective protection systems depending on their intended use [Stanag 2515].

Lp.	Module	CPS level (purpose)			
		Level 1 (Survival shelters)	Level 2 (Implementation of C4I tasks[9])	Level 3 (Repair Workshop)	Level 4 (Provision of rest, hospitals, medical facilities)
1	Control zone		X	X	X
2	Checkpoint		X	X	X
3	Liquid hazard area		X	X	X
4	Changing booth			X	X
5	Dust endangered zone		X	X	X
6	Vapour hazard area		X	X	X
7	Storage zones				X
8	Waste storage zones				X
9	Airlock	X	X	X	X
10	Uncontaminated zone	X	X	X	X
11	A/C module			X	X
12	Oxygen regeneration module			X	X
13	Air recirculation filter			X	X
14	Air filtration unit	X	X	X	X
15	Power module	X	X	X	X

[7] Publication ATP-3.8.1 part 2 places the dust danger zone after the poisonous agent vapor danger zone. In the vapor danger zone, protective footwear and gloves are removed, while in the dust danger zone, final decontamination is carried out (usually with a spray) and the transit mask is removed, which the entrant keeps with him in the uncontaminated zone.

[8] vapour hazard area - in collective protection against contamination, that part of the controlled contamination zone, which is located between the liquid poisonous agent hazard zone and the airlock, in which there is only contamination by vapors of toxic warfare agents. [NO-01-A006, AAP-21].

[9] C^4I – Command, Control, Communications, Computers and Intelligence.

CPSs should be equipped to provide connectivity, both between system components and to the outside world. They may also be equipped with toilets. If part of the building is adapted for collective protection, existing toilets can be used, in other cases covered containers or chemical toilets can be used. CPSs should be equipped with mains-powered (if available) and battery-powered emergency lighting. Lighting should not be overextended as it causes an increase in internal temperature.

3 Ventilation of facilities

The development of civilization, is not only a modern boon, but also a great threat to man and his environment. The threat of diseases of civilization is growing rapidly, which certainly include allergic diseases, asthma and the increasingly common diseases of the upper and lower respiratory tracts. Most of the substances (both chemical, biological and neutral) that cause negative effects in the human body are found in the surrounding air. These include toxic gases and dusts containing bacteria, viruses, fungi and a wide range of chemical compounds (organic and inorganic). The main routes of entry into the human body are the respiratory tract. During normal existence, humans emit carbon dioxide, water vapor, heat and so-called "odors" into the atmosphere. Carbon dioxide is a physically asphyxiating gas (by reducing the partial pressure of oxygen). It is heavier than air and accumulates near the ground and in the lower parts of rooms. At concentrations in the air above 5%, it causes shortness of breath, accelerated breathing and heart rate, headache, motor restlessness, sweating. In concentrations greater than 10%, it causes shortness of breath, visual hallucinations, loss of consciousness. In concentrations above 20%, it causes cardiac arrhythmias, convulsions and death due to respiratory center paralysis. Several hours of exposure to carbon dioxide at concentrations of 1-2% can cause nonspecific symptoms due to acid-base imbalance. The maximum permissible concentration (MPC) of CO_2 in the air is - 9000 mg/m^3 (0,5%), and the instantaneous concentration (MPC) is 27000 mg/m^3 (1,5%). Rooms, therefore, should be ventilated.

Ventilation is the process of removing contaminated air from a room and supplying fresh air in its place. Ventilation is necessary because the air in all rooms is constantly being contaminated. Ventilation of rooms can occur naturally. Thanks to the difference in temperature, and therefore the density of air inside and outside the building, and the action of the wind, air enters the building through leaks in windows and doors or through special ventilators, and escapes through grilles and ventilation ducts. The effectiveness of natural ventilation, also known as gravity ventilation, depends on atmospheric conditions, so it varies throughout the year. The basic type of ventilation is mechanical ventilation. Air exchange is then independent of any atmospheric influences. Forced airflow is achieved through the use of a fan. The advantage of mechanical ventilation is the ability to adjust its performance to the actual needs of the occupants, so you can create comfortable indoor conditions. Mechanical ventilation can have many variations depending on the method of air exchange, the direction of air movement in relation to the ventilated room, the pressure difference inside and outside the room.

Depending on the method of air exchange, mechanical ventilation can be divided into:

- ***general,*** that is, providing an even exchange of air throughout the room,
- ***local***, which counteracts air pollution at the place where it is emitted.

Local ventilation includes such devices as:

- ***local exhausts***, devices used to remove pollutants directly at the place where they originate,
- ***local vents***, used to produce conditions in a specific location that are different from those in the entire room,
- ***air curtains***, used to protect rooms from the penetration of cold outside air (in winter) or hot air (in summer) through frequently opened gates and entrance doors in industrial or public buildings.

Depending on the direction of air movement in relation to the ventilated room, mechanical ventilation is distinguished:

- ***supply*** **-** the supply of air is carried out mechanically, and the removal is carried out naturally,
- ***exhaust*** **-** air is supplied naturally, and mechanically assisted exhaust,
- ***supply-exhaust*** **-** in this case the supply and removal of air is carried out fully mechanically.

Depending on the pressure difference inside and outside the room, ventilation is:

- ***positive pressure***, where the volume flow of supply air is greater than the volume flow of exhaust air,

- ***negative pressure***, where the volume flow of supply air is less than the volume flow of exhaust air.

It is important to realize that mechanical ventilation can be a potential source of natural or intentional contamination or infection (terrorist introduction of substances hazardous to health or life into the ventilation system) with an unprotected air intake. A method of protection is a filtration or filtering system.

In order to reduce the harmful concentration of solid and liquid aerosols (dust, dust, microorganisms, etc.) in the air, the most common method used is filtration:

- filter dust collectors, which trap aerosol particles on filter material;
- electrostatic filters, in which the application of high voltage causes ionization of dusty air and capture of electrostatically charged pollutant particles by oppositely charged electrodes;
- wet dust collectors, comprising various types of equipment in which aerosol particles are deposited on droplets or layers of liquid and are then removed as sludge;
- sedimentation chambers, made up of a number of plates (usually made of charcoal) placed above each other, on which dust particles from the flowing air are deposited;
- cyclones, consisting of a larger tube that tapers downward and a smaller concentric tube inside, in which dust particles fall out of the air stream by centrifugal force;
- lamps emitting ultraviolet radiation with germicidal effect, used to sterilize the air in confined spaces;
- a combined method using two or more techniques, e.g., a cyclone as a pre-cleaning element of the air and filtration by highly efficient HEPA or ULPA class filters (HEPA filters, colloidal aerosol filters of medium and high efficiency, designated H10÷H14, ULPA filters, colloidal aerosol filters of very high efficiency, designated U15÷U17).

In order to reduce the harmful concentration of vapors of highly toxic substances in the air, sorption method is mainly used, for example, on molecular sieves, bentonites, and most often on carbon sorbents. Such devices are called absorbers, and with filter cartridges - filter absorbers. They can provide protection against only one type of toxic agent (such as ammonia or carbon monoxide), multi-gas and universal.

All types of structures should be equipped with ventilation systems, that is, residential, public buildings (banks, railway stations, stores, cinema and conference halls, office buildings, hospitals, etc.). In turn, filter-ventilation systems, should be equipped with structures of a special type or adapted to protect the public from the effects of highly toxic substances - a facility for collective protection. Collective protection facilities are stationary or field-type facilities of both military and civilian use (shelters, hiding places) and mobile facilities (combat vehicles, motor vehicles, ships) specially prepared and adapted to protect people and equipment from the effects of conventional weapons, weapons of mass destruction and contamination with toxic industrial substances.

4 Ways to protect facilities from the penetration of contaminated air [8]

It is very difficult to remove completely the phenomenon of penetration of contaminated air into facilities. To achieve this, it would be necessary to ensure absolute tightness of the facilities, which is practically impossible. Therefore, it is necessary to strive to reduce the amount of air penetrating into the facility as much as possible.

This can be achieved by:

- sealing and closing any openings and gaps created during construction;
- building airtight vestibules in the entrances, giving several degrees of sealing;
- creating a certain air overpressure in the shelter, counteracting the penetration of contaminated air through leaks.

Isolation of the facility is achieved by sealing the following:

- entrances;
- functional openings (firing ranges, places of introduction of various pipes, cables, etc.);
- partitioning surfaces (ceiling, walls, floor).

The most serious difficulty in sealing facilities is sealing entrances. This involves the fact that through the entrance the facility connects to the surrounding atmosphere when the door is opened.

The idea of sealing entrances is to create several airtight partitions with minimal leaks, as well as buffer spaces where dilution of infiltrated contaminated air would take place. In addition, provision should be made to ventilate these spaces with air coming out of the shelter in order to periodically purify the air in them.

The movement of air in doing so should take place in the direction of the contaminated atmosphere. The realization of this idea is achieved by building vestibules with airtight partitions and airtight doors.

The number of vestibules depends on the purpose, volume and type of facility. In simple, small facilities there may be one vestibule with two airtight doors. In large and important facilities, there may be more vestibules. The more vestibules in an entrance, the higher its degree of airtightness, the lower the probability of penetration of contaminated air through the entrance and the longer the time of full isolation of the facility (the period when the filtering device is not working).

However, increasing the number of vestibules increases the consumption of materials, time and manpower, and complicates the operation of facilities. Therefore, in practice, the number of vestibules is limited to minimally unnecessary (most 5).

Let's try to quantify the value of vestibules in reducing the phenomenon of penetration of contaminated air.

Let's consider the penetration of contaminated air into an object having different numbers of atria. According to equation (1), the concentration after time ***t*** will be:

- in the first atrium:

$$C_1 = C_0\left(1 - e^{-\frac{v_1}{W_1}\cdot t}\right) \tag{1a}$$

- in the second vestibule:

$$C_2 = C_1\left(1 - e^{-\frac{v_2}{W_2}\cdot t}\right) \tag{1b}$$

- in the nth atrium:

$$C_n = C_{n-1}\left(1 - e^{-\frac{v_n}{W_n}\cdot t}\right) \tag{1c}$$

- in the shelter:

$$C_{sch} = C_n\left(1 - e^{-\frac{v_{sch}}{W_{sch}}\cdot t}\right) \tag{1d}$$

where:

C_0 - external concentration of the harmful substance;

$v_1, v_2 .... v_n$, v_{sch} - volume of infiltrated contaminated air per unit time in the 1st, 2nd...nth atrium and shelter, respectively;

W_1, W_2,...,W_n, W_{sch} - volume of the 1st, 2nd,...,nth vestibule and shelter, respectively.

Air overpressure in the shelter can be created by dispensing compressed air from cylinders, heating the shelter air and mainly by running the filtering device.

Air overpressure inside the facility is called support and is expressed in mm of water column (now in Pa) - 1 mm of water column = 9.81 Pa.

If there is an overpressure in the shelter, the air continuously goes outside through leaks, and in this case external contaminated air cannot penetrate the shelter.

In sealed field shelters, positive pressures are generated almost immediately when the filtering device is activated and immediately decrease when it is turned off.

The amount of overpressure depends on:

- the tightness of the facility;
- the efficiency of the filter-venting device or the amount of released air from the cylinder.

For any object with constant airtightness, the positive pressure is a function of the air output of the filtering device:

$$\Delta p = f(V) \qquad (2)$$

In practice, it is important to know the value of the required support. In the general case, the support should exclude the possibility of penetration of contaminated air into the object. Therefore, its value should slightly exceed the maximum possible for the object in question operating differential pressure.

For stationary objects, subject to the action of wind, the support should be not less than 5 mm of water column (in practice, about 100 Pa).

For objects that are not affected by wind, a support of 1-2 mm of water column is sufficient (practically about 50 - 100 Pa).

In practice, the size of the support can be adjusted automatically by using appropriate valves, regulating the rate of air flow out of the object.

5 Methods to ensure clean air in facilities [8]

Facilities intended for collective protection should be designed for a relatively long-term stay of people in them, for whom adequate sanitary-hygienic conditions must be provided.

Violation of the specified sanitary-hygienic norms of the facility leads to a decrease in the fitness of people, causes disease, and in some cases can lead to poisoning. The reason for the violation of normal sanitary and hygienic conditions in the premises is the lack of clean air, or more precisely, the violation of its normal composition.

It is known that in unventilated rooms with many people, the air after some time becomes unfit for breathing. It is therefore necessary to continuously supply the facility with a certain amount of clean air. If the outside air is contaminated, it should be cleaned in advance in special filter absorbers.

The need to ventilate facilities is also related to the removal of toxic vapors and gases (carbon monoxide and dioxide, ammonia, protein and fat decomposition products, etc.), as well as excess moisture and heat.

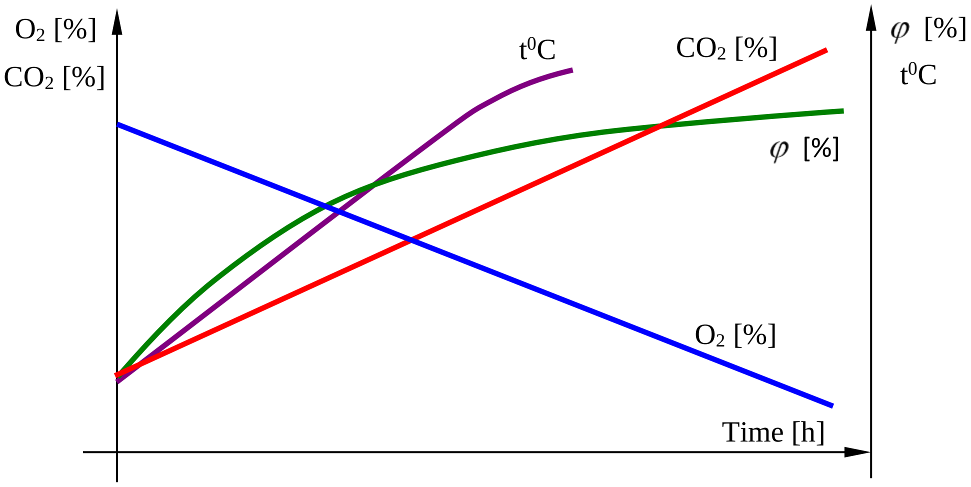
5.1 Change in the composition and properties of air in enclosed spaces [8]

The change in the composition and properties of air in closed, airtight and unventilated rooms, occurring as a result of physiological processes, boils down to:

- a decrease in oxygen content;
- an increase in carbon dioxide content;
- an increase in air humidity;
- an increase in air temperature;
- the appearance of unpleasant odors in the air.

The nature of changes in air composition and properties as a function of time in such rooms is shown in Fig. 1.

Fig. 1. Change in air composition over time in a closed room with people in it.



According to the data of many authors, the amount of carbon dioxide secreted by one person at rest is 18 - 22 dm^3/h, and the amount of oxygen absorbed is 20-28 dm^3/h.

Saturation of air with moisture, as is known, can only occur up to a certain limit, which depends on the air temperature. Thus, for example, at a temperature of 20°C, the saturation state corresponds to the content of 17,7 g of water in 1 m^3 of air. Therefore, when the volume of the room is insufficient, the humidity of the air quickly reaches the saturation state, and the excess moisture condenses on the surface of the ceiling, walls, equipment, uniforms, etc.

The release of heat by the human body is the result of the body's normal work. Most of the secreted heat is dissipated into the surrounding environment as a result of evaporation of moisture from the body surface, heating of exhaled air, and convection and radiation. About 85% of the heat is given off to the environment through the skin. The amount of heat given off by a person in one day is 2,200 ÷ 3,200 kcal (9,211 ÷ 13,398 J).

Consequently, the air in unventilated rooms heats up quickly.

The amount of carbon dioxide released, oxygen absorbed, moisture released and heat released depend on the nature of physical exertion.

Table 2 gives data characterizing these relationships [8]:

Table 2: Average data for 1 person for 1 hour

The nature of the physical effort	The amount of oxygen absorbed dm^3/h	The amount of secreted		
		CO_2 dm^3/h	H_2O g/h	warm kcal/h
Sleep	20-25	16-20	40-50	50
Light intellectual work	25-30	20-25	60-70	75-100
Intensive mental work	do 35	do 30	do 75	100
Manual labor	60-120	50-100	do 130	200-300

In addition to this, attention should be paid to an important phenomenon, which is the formation of unpleasant odors in the room, coming from the decomposition products of organic substances (hydrogen sulfide, ammonia, various acids) and vapors emitted by uniforms and room equipment. Air pollution by these substances can negatively affect human well-being.

In the Regulation of the Minister of Infrastructure of April 12, 2002 on the technical conditions to be met by buildings and their location - annex to the announcement of the Minister of Development and Technology of April 15, 2022 (item 1225) in § 149. 1. The flow rate of external air supplied to rooms that are not work rooms should meet the requirements of the Polish Standard for ventilation, while in apartments the flow rate should be derived from the exhaust air flow rate, but should be no less than ***20 m^3/h per person*** projected for permanent residence in the building design [9].

NATO requirements for collective protection facilities STANAG 2515 (Study) - ATP-70 - Collective protection in a nuclear, chemical and biological environment.

- min. 8,5 m^3/h of fresh air per resting person;
- and min. 17 m^3/h of fresh air per working person.

All of the above-mentioned changes in air properties negatively affect the human body.

Taking into account the toxicity of carbon dioxide and the simultaneous reduction of the oxygen content in the air, the concentration of carbon dioxide in rooms where people stay should not exceed 0,2% for long-term and 0,5% for periodic occupancy.

For less important facilities it is assumed:

- 0,5% for long-term occupancy (MPC);
- 1,0 % for periodic residence;
- 2,0 % for short-term stay in the facility.

Within 1 to 2 hours, a healthy person can be in an atmosphere with a concentration of 3÷3.5 percent CO_2 without repercussions harmful to health. An increase in the concentration of carbon dioxide by 1% corresponds, in fact, to a reduction in oxygen content of 1,15 ÷ 1,20%. However, in practice, there may be cases when the concentration of carbon dioxide in the air will not correspond to the decrease in oxygen content (sorption of CO_2 by lime, cement). In this case, it is necessary to know the limit to which the oxygen content can be reduced. For most cases, this limit is 17% when people are in the facility for a long time.

A great influence on the well-being of people in an enclosed facility has the physical parameters of air, such as temperature and humidity. The lower the ambient temperature, the faster the heat exchange between the body and the environment. At temperatures above 37°C, the body takes in heat from the environment, which can lead to heat stroke.

With increasing humidity, the heat exchange between the body and the environment as a result of evaporation of moisture (sweat), which can lead to overheating of the body. Heat exchange between the body and the environment is also affected by air movement.

At very high humidity and air temperatures close to body temperature, air movement has no cooling effect on the body.

In order to secure normal or acceptable sanitary and hygienic conditions in closed facilities, it is necessary, therefore, to ventilate them by supplying them with a certain amount of purified air.

5.2 The process of ventilating a room [8]

Before determining the amount of clean air supplied to the facility to create normal or acceptable sanitary and hygienic conditions for people, it is necessary to consider the nature of the change in the concentration of harmful admixtures in the ventilated room.

Harmful admixtures of air in the facility may be:

- carbon dioxide, as a product of respiration;
- chemical vapors (e.g., TIM or CWA),
- radioactive and biological aerosols, penetrating or brought by people into the facility;
- carbon monoxide contained in gunpowder gases (fire stations) and engine exhaust gases (in addition, NOx and/or H_2S);
- vapors of combustible materials, solvents, etc.

In the general case, the release of harmful admixtures can occur both before and during ventilation.

In this case, when the concentration of pollutants, constantly flowing in and rapidly mixing with the air of the room, over time reaches a certain maximum value of C_{max}, corresponding to the state of equilibrium between inflow and loss of admixtures. If the facility is ventilated for a sufficiently long period of time with a constant flow rate of clean air, a certain value of maximum concentration is reached, regardless of the size of the initial concentration C_0, produced in the room before the start of ventilation. Suppose that $C_0 < C_{max}$ then, at the beginning, the amount of incoming harmful substance will exceed the amount removed by the air leaving the room, and its concentration will increase until the equilibrium state is reached.

At $C_0 > C_{max}$, at the beginning the amount of substance removed from the air will exceed the amount flowing in, and this will continue until equilibrium is reached. Accordingly, in this case, the concentration of the admixture will decrease up to the value of C_{max}. At $C_0 = C_{max}$, the admixture concentration will not change for any length of ventilation time, and at $C_0 = 0$ there will be an increase in admixture concentration, as in the first case.

For the steady state, when the dopant concentration has reached its maximum value, the following mass balance equation can be written:

$$m = V \cdot C_{\max} \tag{3}$$

where:

m - amount of harmful admixture, uniformly reach the ventilated room per unit time, in g/h;

V - amount of clean air supplied by the filtering equipment per unit of time, in m^3/h;

C_{max} - maximum concentration of harmful admixture in the ventilated room, in g/m^3.

From this equation, it follows that C_{max} depends only on m and V. By varying these quantities, different values of C_{max} can be obtained:

$$C_{\max} = \frac{m}{V} \tag{4}$$

The amount of clean air needed to ventilate the room will be:

$$V = \frac{m}{C_{\max}} \tag{5}$$

The above formulas allow you to determine only the final result of the ventilation process. With their help, it is not possible to determine the concentrations of the admixture at any time and the time to reach the maximum concentration. In addition to this, it is also necessary to consider the ventilation process under conditions where the harmful admixture does not enter the room during ventilation, and the task is reduced only to removing the admixture already in the room.

In order to derive the relevant equations, we will introduce the following assumptions:

- the harmful admixture emitted in the room immediately mixes
- with the entire volume of air in the room;
- the air coming from outside into the room does not contain the noxious admixture;
- the noxious admixture does not sorb on the structural elements of the room, equipment and uniforms;
- the air temperature remains constant;
- mixing of the air coming into the room is immediate.

In a room with a volume W in m^3, there is an admixture with a concentration of C_0 in g/m^3 until ventilation begins, and after ventilation begins, the admixture enters the room uniformly in the amount of m in g/h. At the same time, clean air is supplied to the room in the amount of V in m^3/h. After time $t(h)$, the admixture concentration in the room was C in g/m^3.

During ***dt***, admixture enters the room $m \cdot dt$ in g and exits out of the room as a result of ventilation $C \cdot V \cdot dt$ in g.

The change in the amount of admixture in the room at time ***dt*** will therefore be:

$$W(C + dC) - WC = WdC \tag{6}$$

The mass balance equation will be of the form:

$$mdt - VCdt = WdC \tag{7}$$

lub

$$\frac{dC}{m - VC} = \frac{1}{W}dt \tag{8}$$

Integrating this equation in the concentration intervals from C_0 to C and time from 0 to t, we get:

$$\int_{C_0}^{C} \frac{dC}{m - VC} = \frac{1}{W}\int_{0}^{t} dt \tag{9}$$

$$\frac{1}{V}\ln\frac{m - VC_0}{m - VC} = \frac{1}{W}t \tag{10}$$

Substituting instead of $\frac{V}{W} = k$ - exchange intensity factor, we get:

$$\frac{m - VC_0}{m - VC} = e^{-kt} \tag{11}$$

stąd

$$C = \frac{m}{V}\left(1 - e^{-kt}\right) + C_0 e^{-kt} \tag{12}$$

lub

$$C = \frac{m}{kW}\left(1 - e^{-kt}\right) + C_0 e^{-kt} \tag{13}$$

If ***C*** is expressed in % and ***m*** in dm^3/h then equation (12) will be of the form:

$$C = \frac{m}{10V}\left(1 - e^{-kt}\right) + C_0 e^{-kt} \tag{14}$$

$$C = \frac{m}{10kW}\left(1 - e^{-kt}\right) + C_0 e^{-kt} \tag{15}$$

Equations (12 ÷ 15) characterize the general relationship of the change in concentration of any harmful substance over time in a ventilated room.

At t = 0; C = C_0; and at t $\to \infty$:

$$C = \frac{m}{V} = C_{\max} \tag{16}$$

5.3. Determination of the necessary amount of air for ventilation of premises

We will consider ways to determine the amount of clean air needed to combat harmful admixtures and to ensure adequate sanitary and hygienic conditions in facilities.

a/ Determination of the amount of clean air needed to support a fixed concentration of carbon dioxide

Quantitative standards of clean air supply, per person can be determined by starting from the maximum permissible concentration of carbon dioxide $\boldsymbol{C_{max\,dop}}$ based on the following relationship (when the concentration is expressed in % and $\boldsymbol{m}$ in dm^3/h):

$$V = \frac{m}{10C_{\max dop}} \tag{17}$$

In practical calculations, the carbon dioxide content of ambient air (about 0,03%) is usually not taken into account.

Depending on the assumed value of $\boldsymbol{C_{max\,dop}}$ and the value of $\boldsymbol{m}$ for different types of exercise, we will get the values of $\boldsymbol{V}$, shown in Table 3 [8].

Table 3: Clean air requirements for 1 person for 1 hour due to CO_2 concentration.

Type of physical effort	m dm^3/h	$C_{max\,dop}$, %					
		0,2	0,5	1,0	1,5	2,0	2,5
		V m^3/h					
Tranquility (relaxation)	20	10,0	4,0	2,0	1,33	1,0	0,8
Mental work	25	12,5	5,0	2,5	1,67	1,25	1,0
Hard mental work	30	15,0	6,0	3,0	2,0	1,5	1,2
Physical work	50	25,0	10,0	5,0	3,3	2,5	2,0
Intense physical exertion	100	50,0	20,0	10,0	6,7	5,0	4,0

With an increase in air delivery standards, the concentration of CO_2 in the air will decrease accordingly.

b/ Determination of the amount of clean air needed to support the established oxygen concentration

The oxygen concentration in the room is determined from the relationship:

$$C = 21 - \frac{a}{10V}\left(1 - e^{-kt}\right) \tag{18}$$

Where $\boldsymbol{a}$ is the amount of oxygen consumed by one person in dm^3/h.

For t $\to \infty$ the limiting concentration will be:

$$C_\infty = 21 - \frac{a}{10V}$$

hence

$$V = \frac{a}{10(21 - C_\infty)} \tag{19}$$

Table 4 gives $\boldsymbol{V}$ values in m^3/h for different values of $\boldsymbol{a}$ and $\boldsymbol{C}$ [8].

Table 4: Clean air demand for 1 person for 1 hour due to oxygen

Type of physical effort	a dm³/h	C, %				
		20,5	20	19	18	17
		V, m³/h				
Tranquility (relaxation)	25	5,0	2,5	1,25	0,84	0,63
Mental work	30	6,0	3,0	1,5	1,0	0,75
Hard mental work	35	7,0	3,5	1,75	1,2	0,88
Physical work	60	12,0	6,0	3,0	2,0	-
Intense physical exertion	120	24,0	12,0	6,0	-	-

From the tables shown, it can be seen that for the same physical exertion, relatively less clean air is needed to sustain a high concentration of oxygen (19-20%) than for a low concentration of CO_2.

c/ Determination of the amount of air needed to remove excess water vapor

In this case, ventilation technology uses the following formula:

$$V = \frac{M}{\gamma(\varphi_{wew} - \varphi_{zew})} \tag{20}$$

where:

M - mass of water vapor that should be removed from the air in g per hour;

φ_{wew} - absolute humidity of indoor air in g/kg;

φ_{zew} - absolute humidity of outdoor air in g/kg;

γ - density of air in kg/m^3.

From the analysis of this example, it can be concluded that when the absolute humidity of the outside air is low, it is not difficult to remove excess humidity from the room.

d/ Determination of the amount of air needed to remove excess heat

In order to approximate the amount of air needed to remove excess heat in ventilation technology, the following formula is used:

$$V = \frac{Q_1 - Q_2}{C(T_2 - T_1)\rho} \tag{21}$$

where:

Q_1 - the total amount of heat released in the room by people, apparatus and equipment in kcal/h;

Q_2 - heat loss of the facility in kcal/h;

T_1 - temperature of air fed into the room in K;

T_2 - required temperature of air in the room in K;

C - specific heat of dry air equal to 0,24 kcal/kg·K;

ρ - density of air in kg/m^3.

5.4. Ways of supplying clean air to a facility [3].

The supply of clean air to facilities can most rationally be implemented using various ventilation systems. The following ventilation systems can be used in rooms built for collective protection facilities:

- supply- exhaust;
- supply and exhaust;
- recirculating.

Supply ventilation is based on the principle of supplying the ventilated room with external air, cleaned in special filters from poisonous, radioactive and biological substances. This system is called filter ventilation and is used in most collective protection facilities. Such facilities are called ventilated, and the air supply equipment is called filtering equipment.

During the operation of these devices, clean air is continuously fed into the facility and mixed with indoor air. The injected air creates some slight overpressure (support), under the influence of which the mixed air leaves the room to the outside through valves and other leaks, ventilating the atriums. A diagram of the facility's supply ventilation is shown in Fig. 2.

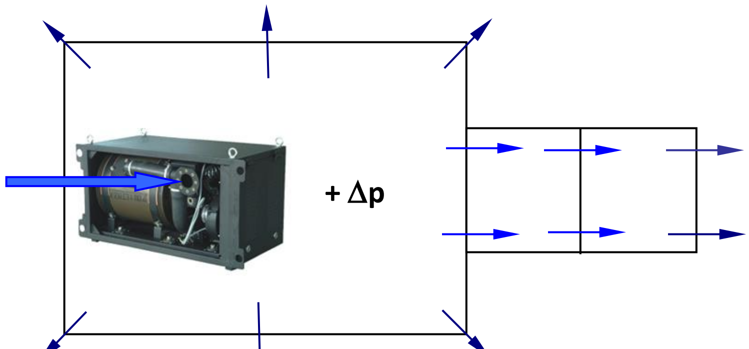


Fig. 2. Schematic of supply ventilation

The supply and exhaust system is a combination of filter and exhaust ventilation, with exhaust ventilation having a slightly lower capacity than supply ventilation to create positive pressure in the room.

This system is used in most permanent, fortification and special facilities and is more efficient than the supply system. However, this system has some disadvantages in that there may be a danger of contamination of the facility if the supply system fails unexpectedly. Therefore, in this case, automatic shutdown of exhaust ventilation must be provided. Separate exhaust devices can be installed in such rooms as sanitary hubs, battery rooms, warehouses, etc. A diagram of supply and exhaust ventilation is shown in Fig. 3.

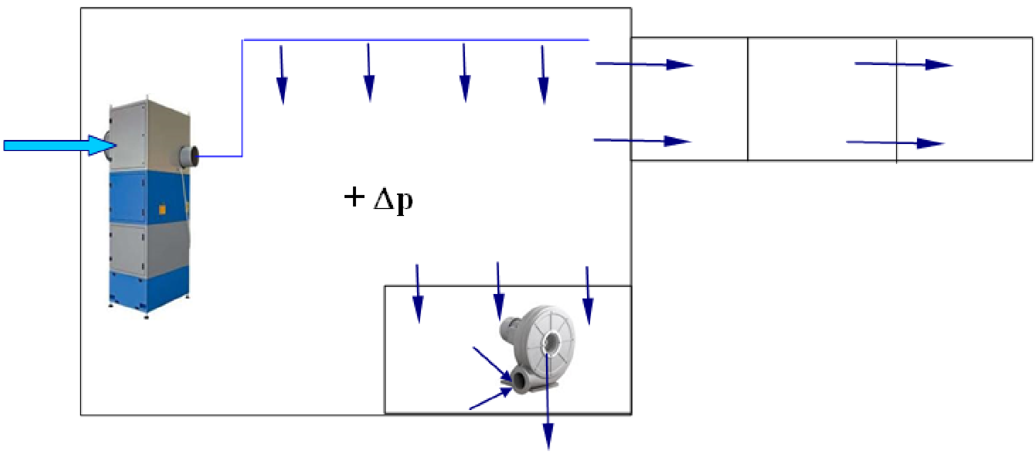


Fig. 3. Supply and exhaust ventilation scheme

The recirculation system provides closed air movement in the rooms. Recirculation can be total or partial.

With partial recirculation, a certain amount of indoor air is drawn in through a filtering device (Figure 4).

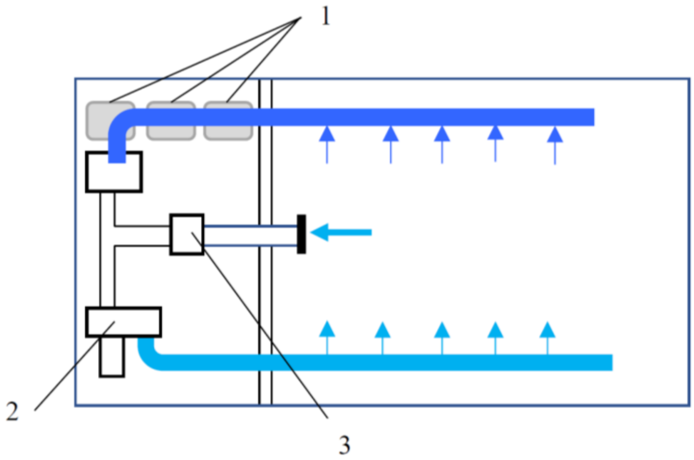


Fig. 4. Diagram of partial and total recirculation of air in the facility:

1-regenerative equipment; 2-fan; 3-valve regulating the intake of recirculating air

The use of partial recirculation is expedient in large facilities where cooling and dehumidification equipment can be set up.

With complete recirculation, the indoor air is cleaned of carbon dioxide and enriched with oxygen in oxygen-regeneration equipment. In addition, air conditioning equipment can be installed in large facilities.

The condition for the use of a system of total air recirculation must be the complete isolation of the premises from the surrounding atmosphere. In order to maintain a slight overpressure (support) in the facility, compressed air in cylinders is used (Fig. 5) [10,11,12].

Fig. 5. Compressed air reservoirs in a fixed defense facility

At the same time, it should be emphasized that this system may not be the only one in the facility. It is generally a backup system, used when it is impossible to use a supply air filtering system, such as when it is not known what the outside air is contaminated with, or when the filtering equipment cannot work for any reason.

With the help of regeneration equipment, in principle, it is possible to obtain air with any assumed carbon dioxide and oxygen content, and with the help of air-conditioning equipment - also with a certain humidity and temperature.

The advantage of this air purification system is its independence from the state of the external atmosphere. In a well-sealed and strong facility, it provides long-term protection against any poisonous, radioactive and biological agents.

However, it should be borne in mind that filter-ventilation systems are calculated for longer periods of operation and are therefore cheaper than regenerative systems.

Facilities with no ventilation system are called unventilated.

The certainty of protection in such facilities is based on good sealing

and the exclusion of people entering or leaving when the atmosphere surrounding the facility is contaminated. The residence time of people in such facilities is calculated starting from consideration of the permissible concentration of carbon dioxide in the facility, the number of people in the facility, the volume and purity of the air in the facility.

The residence time of people in an unventilated facility is determined from the formula:

$$t = \frac{10(C_d - C_0)}{m \cdot N} W \qquad (22)$$

where:

C_d - the allowable concentration of CO_2 in %;

C_0 - the concentration of CO_2 in the room at the start of its operation in %;

m - amount of CO_2 released by 1 person dm^3/h;

N - number of people;

W - volume of air in the room in m^3;

t - residence time of people in the room.

5.5. Means of regeneration and purification of air in conditions of total isolation of objects [8].

Under conditions of modern warfare, there will be possible cases where the supply of outside air to the facility will be impossible over an extended period of time due to fires in the surrounding area or damage and obstruction of air intakes.

Under these conditions, facilities must have the means to regenerate the chemical composition of the air and the means to purify the air from various harmful admixtures emitted inside the facility during the operation of various equipment and apparatus.

Complete isolation for a long period of time is possible only in the case of well-sealed facilities, while in such facilities it is necessary to constantly maintain a slight air overpressure ("support"), using, for example, compressed air in cylinders.

Oxygen-regeneration devices are used to regenerate the chemical composition of the air, while various specific filters are used to remove harmful admixtures from the air.

It is also necessary to remember about the appropriate humidity and temperature of the air inside the facility. For this purpose, appropriate air-conditioning devices are used in the facilities.

Oxygen-regeneration devices are used only in large and important facilities.

In field and mobile facilities, oxygen-regeneration devices are not used due to their limited airtightness.

Oxygen-regeneration devices are designed to purify air from carbon dioxide and enriching the air with oxygen.

Various liquid and solid chemical absorbers are used to absorb carbon dioxide, containing e.g.: KOH, NaOH, $Ca(OH)_2$, $K_2(CO_3)_2$, amines, peroxides of potassium and sodium peroxides.

Alkaline canisters (liquid and solid) have good activity against carbon dioxide and give off some water and heat by reaction:

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O + 29{,}8kcal$$
$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O + 28kcal$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O + 18{,}9kcal$$

Due to the lower thermal effect of the reaction, calcium hydroxide is most often used in regeneration equipment. The calcium absorber has the following composition:

$Ca(OH)_2$ - 80 %;

NaOH - 2 %;

H_2O - 18 %.

The use of a chemical absorber containing potassium carbonate is based on the following reaction:

$$K_2CO_3 + H_2O + CO_2 \rightarrow KHCO_3 + Q$$

The advantage of these absorbers is that by heating they can be regenerated, so they can be used repeatedly.

Absorption of CO_2 is often accompanied by the release of oxygen (Na_2O_2, NaO_2, K_2O_2, KO_2 and other peroxides). The air in a facility can be enriched with oxygen by the following means:

- by release from a cylinder;
- by separation through chemical reactions;
- by using liquid oxygen.

Releasing oxygen from a cylinder is the simplest way to supply oxygen. However, the low utilization rate of cylinders (by weight) forces the search for more efficient methods of obtaining oxygen.

The release of oxygen by chemical reactions is the most widely used in recent times. Peroxides and superoxides of potassium and sodium are used for this purpose, from which oxygen is emitted by reaction with carbon dioxide or water:

$$2Na_2O_2 + 2CO_2 \rightarrow 2Na_2CO_3 + O_2 + Q_1$$
$$4NaO_2 + 2CO_2 \rightarrow 2Na_2CO_3 + 3O_2 + Q_2$$
$$4NaO_2 + 2H_2O \rightarrow 4NaOH + 3O_2 + Q_3$$

The use of liquid oxygen is more promising than the use of oxygen in cylinders or chemically bound oxygen, since 1 dm^3 of liquid oxygen when evaporated can yield 790 dm^3 of gaseous oxygen.

6 Conclusions

The geopolitical situation in the world does not inspire optimism. The threat of the use of weapons of mass destruction exists despite the concluded international agreements and conventions. An element of the protection of the population and troops from the impact of contamination, but also conventional weapons, are collective protection measures previously prepared and equipped. Facilities for collective protection are stationary or field-type facilities of both military and civilian use (shelters, hiding places) and mobile facilities (combat vehicles, motor vehicles, ships) specially prepared and adapted to protect people and equipment from the effects of conventional weapons, weapons of mass destruction and contamination with toxic industrial substances. One such element is the facility's ventilation system.

In collective protection facilities is a necessity, since it is anticipated that people will be present for an extended period of time, so there is a need to provide clean air and "expel" from the facility the excess concentration of CO_2, water pore and so-called odors. In addition, if the facility will be operating in the so-called "total isolation mode" it will be necessary to chemically absorb CO_2 and water vapor and replenish the atmosphere with oxygen.

NATO requirements (ATP-70) indicate that any facility, regardless of its purpose, should be of the positive-pressure type with a filter-ventilation device (UFW). The filter-ventilation devices are primarily designed to provide clean air to the facility, maintain positive pressure and ventilate them. The selection of the UWF will be mainly dictated by its capacity, and this will be closely related to the number of people in the facility, the number of planned exchanges and the height of the so-called "support" (positive pressure).

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