Оглавление

INTRODUCTION

The purpose of mastering the discipline ‘Heating, ventilation and air conditioning’ is to form students’ competences in the field of heat and gas supply and ventilation. As part of the study of the discipline students should acquire skills in the selection of regulatory and normative and technical documents, the composition and sequence of works on the design of engineering systems of life support in accordance with the terms of reference for design, standard design solutions and technological equipment of the main engineering systems of life support of the building in accordance with the terms of reference. As part of the coursework, the student must complete a design and calculation task for the heating and ventilation system of an apartment building, as well as the laying of an external heating network and the selection and placement on the situation plan of a modular boiler house and a gas regulating station.

1. BUILDING PHYSICS AND BUILDING CLIMATOLOGY

Addressing the challenge of achieving an optimal indoor microclimate necessitates a tiered approach, encompassing internal, transitional, and external considerations. The internal aspect primarily concerns the architectural design and engineering of building systems, focusing on their inherent capabilities. Concurrently, the edge task involves evaluating and enhancing the properties of the building's envelope, improving its performance as a thermal barrier.

These parameters are achieved through a combination of passive elements, such as structural materials and envelope design, and active systems, which regulate temperature and ventilation. The external dimension centers on mitigating the impact of external environmental variables on occupants. Crucially, the building acts as a shield, protecting individuals from adverse environmental conditions and maintaining a habitable interior.

The ecological diversity and environmental attributes of our nation are unparalleled. Contemporary building practices address a wide spectrum of structural demands, focusing on robustness, longevity, and resilience against disruptive forces. Given the significant financial investment associated with infrastructure development and upkeep, a dual-tiered approach to microclimate normalization is implemented across diverse project objectives. This approach delineates between mandatory, or permissible, and advisable, or optimal, parameters. Typically, ventilation and heating systems are deployed to maintain permissible environmental conditions. Conversely, air conditioning systems are employed to achieve the more stringent optimal parameters, ensuring enhanced occupant comfort and process efficiency.

In addition to understanding what kind of building we are constructing and what parameters of the internal microclimate we need to maintain in it, it is extremely important to understand where exactly this building is being constructed. For example, the duration of the heating period: the estimated period of time of operation of the heating system of the building, which is the average statistical number of days per year, when the average daily temperature of the outside air is consistently equal to and below 8 C or 10 °C, depending on the type of building, for Sochi corresponds to 93 days at an average temperature of the heating period of 6.6 °C, for Moscow 204 days at –2.2 °C, and in the city of Dixon in the Krasnoyarsk Territory 366 days at –11.2 °C. Undoubtedly, these factors will affect the design features of the constructed objects and their thermophysical properties, on which will directly depend on the functions of protection from the negative effects of the environment on humans.

Such factors of interaction with the environment such as air and moisture filtration through the building envelope loopholes have a great impact on the building's internal microclimate parameters.

The main normative and technical document regulating climatic parameters is [1]. This set of rules establishes climatic parameters that are used in the design of buildings and structures, heating, ventilation, air conditioning, water supply systems, in the planning and development of urban and rural settlements of the Russian Federation.

Main climatic parameters of the cold period of the year [1]:

$t_5^{0.92}$ – air temperature of the coldest five-day period with a security of 0,92, °C;

t_{hp} – average outdoor air temperature of the period with average daily air temperature ≤ 8 °C (heating period), °C;

z_{hp} – average duration of the heating period, days;

$v_{\max}$ – the maximum mean wind speeds by rumbles for January, m/s;

φ_{hp} – average monthly relative humidity of the coldest month, %.

Building envelopes act as barriers separating interior spaces from the external surroundings, yet they concurrently facilitate heat and moisture transfer, permitting air infiltration and exfiltration. The responsibility of upholding a specific thermal environment within the building's confines, which includes regulating air temperature, humidity, air velocity, and radiant temperature, rests upon the integrated heating, ventilation, and air conditioning (HVAC) systems. However, it is impossible to determine the thermal capacity and mode of operation of these systems without considering the influence of thermal and moisture protection and thermal inertial properties of enclosures. Therefore, the system of room microclimate conditioning includes all engineering means that provide a given microclimate of the serviced premises: building envelopes and engineering systems of heating, ventilation and air conditioning. Thus, a modern building is a complex interconnected system of heat and mass transfer – a single energy system.

Thermal conduction represents a mode of energy transfer where heat is exchanged between adjacent, non-moving constituents within a substance, whether solid, liquid, or gas. This process involves the transmission of thermal energy through direct contact between the constituent particles or structural elements of the material medium. Analyses of thermal conductivity typically treat the substance as a continuum, neglecting its discrete molecular structure.

Pure thermal conduction is predominantly observed in solid materials, as maintaining complete stasis within liquid and gaseous systems is exceptionally challenging, which makes convection unavoidable. A practical example of conductive heat transfer occurs within the layers of a building's external envelope, where heat flows through materials like insulation and brick.

Heat transfer via the movement of material constituents is termed **convection**. This phenomenon is exclusive to fluids (liquids and gases) and also occurs at the interface between a fluid and a solid surface.The mechanism involves both the bulk transport of energy and the diffusion of heat. In the vicinity of a solid boundary, the interplay between convection and heat conduction is collectively known as convective heat transfer. This near-surface region, termed the boundary layer, is where the thermal resistance to heat exchange is concentrated.

Thermal radiation, a mode of heat transfer, involves the exchange of thermal energy between surfaces via electromagnetic waves that propagate through a medium transparent to such radiation. Upon absorption by a surface, these electromagnetic waves are converted into thermal energy, resulting in a temperature increase. This mechanism differs significantly from conduction and convection, as it does not necessitate a material medium for heat propagation. The rate of radiative heat transfer is governed by the Stefan-Boltzmann law, which correlates it to the absolute temperatures of the emitting and absorbing surfaces and their respective emissivities.

Air leakage into a building's interior space via apertures in the external enclosure, driven by naturally occurring pressure differentials induced by buoyancy and wind, is termed **infiltration**. Conversely, **exfiltration** refers to the outflow of indoor air through these same envelope discontinuities. This phenomenon significantly impacts energy consumption for heating and cooling.

The magnitude of infiltration is contingent upon factors such as the building's airtightness, prevailing weather conditions, and the height of the structure, influencing pressure gradients. Effective management of infiltration is critical for optimizing indoor environmental quality and reducing energy waste in buildings.

The main normative and technical document in the field of thermal protection of buildings is [2].

This code of practice lists three requirements for the thermal envelope of a building:

• **Element-by-element requirements** (the reduced heat transfer resistance of individual envelope structures should not be less than the standardized values). The basic value of the required resistance to heat transfer is standardized for each type of enclosing structure (whether it is a wall, window, attic floor or ceiling over unheated underground) depending on the purpose of the object (residential, pre-school or medical and preventive), as well as the value of degree days of the heating period, HDD, (°C·day)/year (table 1.1).

Table 1.1

Baseline values of the required heat transfer resistance of envelope structures

Buildings and premises, coefficients *a* and *b*	HDD, °C·day/year	Basic values of the required heat transfer resistance R_{req}, (m·°C)/W, of enclosing structures		
		Walls	Ceilings of attic floors, over unheated cellars and basements	Windows and balcony doors, shop windows and stained glass windows
1	2	3	4	5
Residential, medical, preventive and child care institutions, schools, boarding schools, hotels and hostels	2000	2,1	2,8	0,49
	4000	2,8	3,7	0,63
	6000	3,5	4,6	0,73
	8000	4,2	5,5	0,75
	10000	4,9	6,4	0,77
	12000	5,6	7,3	0,80
a	–	0,00035	0,00045	–
b	–	1,4	1,9	–

The value of HDD is calculated according to the data on the average multiyear values of duration (z_{hp}) and average temperature of the heating period (t_{hp}). HDD is one of the main climatic parameters used at the stage of construction design of building envelopes. The value of the HDD is calculated by multiplying the difference between the indoor comfort temperature (t_i) for a particular purpose and the average outdoor air temperature for the heating period by the duration of the heating period:

$$HDD = (t_i - t_{hp})\, z_{hp}. \qquad (1.1)$$

• **Sanitary and hygienic requirement** (the temperature on the internal surfaces of the enclosing structures should not be lower than the minimum permissible values).

• **Complex requirement** (specific heat protection characteristic of the building must not be greater than the normative value). **The specific heat protection characteristic of a building** is the amount of heat equal to the heat energy losses through the thermal protective shell of the building of a unit of heated volume per unit of time at a temperature difference of 1 °C:

$$k_{sp}^{req} = \frac{0.16 + \frac{10}{\sqrt{v_h}}}{0.00013 \cdot HDD + 0.61}, \ \text{W/(m}^3\cdot{}^\circ\text{C) at } v_h > 960 \text{ m}^3. \qquad (1.2)$$

The main normative documents regulating the issues of ensuring indoor microclimate and its comfort in the Russian Federation are currently:

• GOST (Government Standart) 30494-2011 Residential and public buildings microclimate parameters for indoor enclosures [3];

• GOST Government Standart) 12.1.005-88 General sanitary requirements for working zone air [4].

Optimal microclimate conditions represent a specific set of environmental factors that, through sustained exposure, maintain human thermal equilibrium. These parameters ensure minimal activation of thermoregulatory processes while simultaneously fostering a subjective sense of well-being for the majority (at least 80 %) of occupants within a defined space. The optimization of these factors minimizes physiological stress and maximizes comfort.

Permissible parameters of microclimate are combinations of values of microclimate indicators, which in the chronic or repeated exposure outside these ranges may elicit subjective discomfort and reduced performance. These conditions trigger increased thermoregulatory effort, potentially leading to physiological. Critically, microclimates within permissible parameters are defined as not inducing demonstrable harm or irreversible decline in physiological health. They are specifically controlled to avoid detriment to health even through prolonged exposure.

According to [5] in the cold period of the year in the service area of public and administrative buildings or in the working area of production facilities should be taken the air temperature minimum of the permissible temperatures in the absence of excess heat in the rooms or within the permissible parameters in rooms with excess heat.

Also, in [3] optimal and permissible norms of temperature, relative humidity and air velocity in the served zone of premises of residential buildings and dormitories are given (table 1.2). According to [5] in the cold period of the year in the served zone of residential premises the air temperature should be taken according to the optimal parameters, air velocity and relative humidity within the permissible values.

Air parameters in the premises of industrial buildings are defined by [4]. In accordance with the requirements of this standard, optimal microclimate indicators apply to the entire working area, permissible indicators are set differentiated for permanent and non-permanent workplaces. The establishment of these permissible values acknowledges the inherent constraints present in certain industrial processes. Specifically, processes involving high heat generation (e.g., foundries, glass manufacturing) or exposure to extreme environmental conditions (e.g., cold storage facilities, outdoor construction sites) may necessitate deviations from optimal microclimate parameters. These deviations are, however, rigorously controlled and monitored to minimize potential adverse health effects on workers, as outlined in regulations pertaining to occupational safety and health.

Table 1.2

Optimal and permissible norms of temperature, relative humidity and air velocity in the service area of residential and dormitory premises

Period of the year	Permises	Air temperature, °C		Resulting temperature, °C		Relative humidity, %		Air movement speed, m/s	
		Optimal	Permissible	Optimal	Permissible	Optimal	Permissible, no more	Optimal	Permissible, no more
Cold	Living room	20–22	18–24	19–20	17–23	45–30	60	0.15	0.2
	Living room in areas with the temperature of the coldest five day period (0.92 security level) of –31 °C and below	21–23	20–24	20–22	19–23	45–30	60	0.15	0.2
	Kitchen	19–21	18–26	18–20	17–25	–	–	0.15	0.2
	Toilet	19–21	18–26	18–20	17–25	–	–	0.15	0.2
	Bathroom, combined bathroom	24–26	18–26	23–27	17–26	–	–	0.15	0.2
	Inter-apartment corridor	18–20	16–22	17–19	15–21	45–30	60	0.15	0.2
	Lobby, stairwell	16–18	14–20	15–17	13–19	–	–	0.2	0.3
	Storerooms	16–18	12–22	15–17	11–21	–	–	–	–
Warm	Living room	22–25	20–28	22–24	18–27	60–30	65	0.2	0.3

Example of calculations

Description of the object:

– Residential Building (fig. 1.1).
– Number of floors: 5.
– Typical floor height: h = 3 m.
– The basement and attic are unheated.
– Heated volume: V_h = 5897.01 m^3.
– Construction region: Moscow.

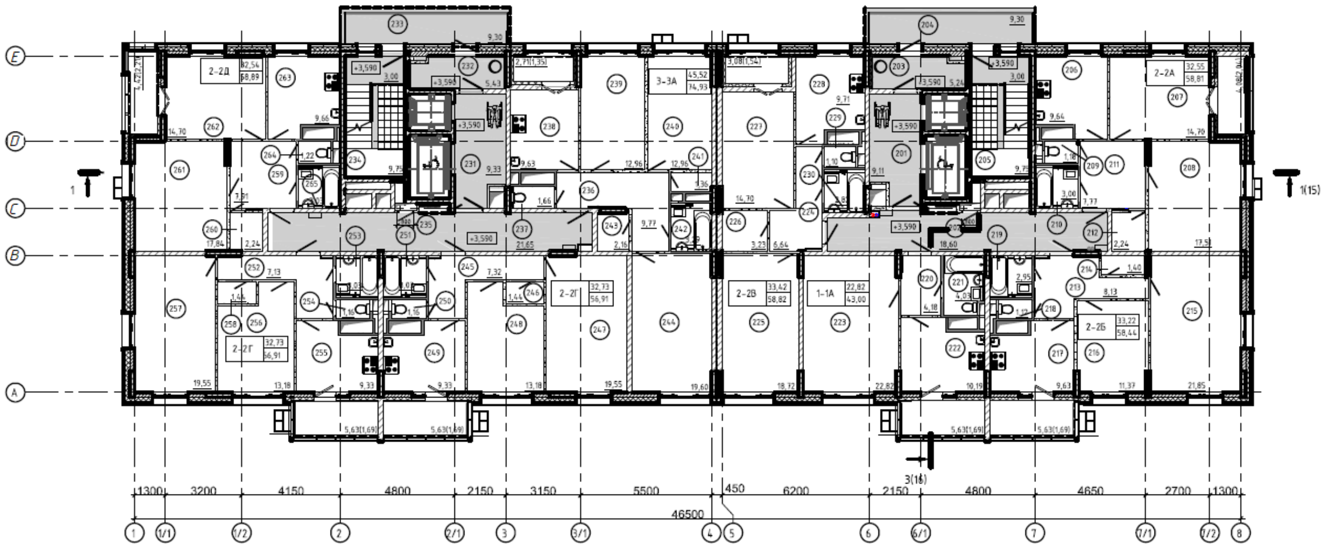

Fig. 1.1. Plan of the residential building

According to [1]:

1. Calculated outside air temperature for the heating system, equal to the average temperature of the coldest five-day period with a probability of 0.92: $t_5^{0.92}$ = –26 °C.
2. Average outside air temperature during the heating period: t_{hp} = –2.2 °C.
3. Average duration of the heating period: z_{hp} = 204 days.

According to [2] average air temperature inside the building, t_i = 20 °C.

Heating Degree Day of the heating period, HDD, ° C·day /year:

$$HDD = (t_i - t_{hp})\, z_{hp} = \big(20 - (-2.2)\big)\, 204 = 4529 \text{ °C days/year}.$$

2. DETERMINATION OF THERMAL POWER FOR THE HEATING SYSTEM

Determination of the heat output of the heating system is carried out after drawing up the heat balance equation for each of the rooms of the building:

$$Q_{premise} = Q_{tr} + Q_{inf} - Q_{domestic}. \tag{2.1}$$

Transmission heat loss Q_{tr}, W, is the loss of heat through enclosures due to heat transfer. Heat transfer is the process of transferring heat from one point of space to another due to temperature differences. In engineering calculations, the transmissive heat loss of each room is calculated by summing the heat loss through each heat losing enclosure. Transmission heat loss depends not only on the temperature difference 'before' and 'behind' the envelope in question, but also on its characteristics: area and heat transfer coefficient, as well as some additional heat losses.

Transmission heat losses of the room, Q_{tr}, W, are calculated by the formula:

$$Q_{tr} = k_{sp}^{req} \cdot v_h (t_i - t_5^{0,92}). \tag{2.2}$$

Heat consumption for heating of the infiltrated air, W:

Q_{inf} – heat consumption for heating of the infiltrated air, W:

$$Q_{inf} = 0.1\, Q_{tr}. \tag{2.3}$$

As mentioned earlier, infiltration is the process of penetrating outside air into the building through gaps in the building envelope, e.g. windows. Infiltration occurs in the zone where the outside air pressure is greater than the internal air pressure in the building. The flow rate of outside air entering the premises as a result of infiltration under design conditions depends on the volume-planning solution of the building, the density of windows, balcony doors, stained glass windows. The task of engineering calculation for each room is reduced to determining the infiltration air flow rate G, kg/h, through the individual enclosures of the room. The quantification of infiltration through building envelopes, though often diminutive in comparison to ventilation, is a critical parameter in accurate energy modeling. The velocity at which air enters a building is governed by a multifaceted interaction of variables. These encompass wind-induced pressure, temperature gradients generating buoyancy-driven flows (known as stack effect), and the innate porosity of building components. While simplified methods may neglect envelope infiltration due to its relatively small contribution compared to fenestration leakage, advanced simulations utilizing computational fluid dynamics (CFD) are increasingly employed to model airflows and predict infiltration with greater precision. These simulations account for the spatial variability of pressure coefficients on building facades and the complex geometry of cracks and openings. Regarding open doors and gates, the heat loss calculation deviates significantly from the closed-state scenario. Rather than relying on leakage coefficients, the open-state heat loss is primarily driven by convective heat transfer and air exchange resulting from direct exposure to the ambient environment. This heat loss is often modeled as an addition to the baseline conductive heat transfer and infiltration occurring when the door is closed. The magnitude of this addition is highly dependent on the frequency and duration of door openings, as well as the temperature difference between the interior and exterior environments.

Heat costs for heating the outside air entering the premises due to the organized influx through window valves, vents, transoms and other devices for ventilation of the premises, i.e. heat consumption for heating the air necessary to compensate for natural exhaust from the premises, Q_{in}, W:

$$Q_{in} = 0.278 \cdot C_i \cdot \rho_i \cdot A_i \cdot l\,(t_i - t_5^{0.92}), \tag{2.4}$$

where A_i – is the floor area of the living room, m^2;

l – specific supply air flow rate equal to 3 m^3/h per one m^2 of living space, if the total area of the apartment is not more than 20 m per person;

C_i – mass heat capacity of air, equal to 1.005 kJ/(kg·°C);

ρ_i – density of indoor air, kg/m^3.

Domestic heat emissions into the room, $Q_{domestic}$, W:

$$Q_{domestic} = 17\, A_l. \tag{2.5}$$

Notes:

1. Domestic heat emission into the room $Q_{domestic}$, W, is determined only for living rooms and kitchens.
2. If a residential building has natural exhaust ventilation and unorganized supply of outdoor air, the larger of the two values Q_{inf} or Q_{in} is substituted into the heat balance equation for residential premises.
3. If the residential building has a mechanical ventilation system, the value Q_{inf} is substituted into the heat balance equation.

3. DESIGN OF APARTMENT HEATING SYSTEM

3.1. Technical solution

In cold climates a heating system is an essential part of creating comfortable internal environments.

Components of heating systems:

• Heat source (to generate heat).

• Distribution medium and network (to distribute the heat around the building).

• Heat emitters (deliver the heat to the space).

The fundamental principle of a horizontal heating system revolves around distributing heated fluid, through a network of pipes running predominantly along a horizontal plane. This contrasts with vertical systems, where risers distribute the fluid upwards through multiple stories. In a horizontally oriented design, each heating element, such as a radiator or baseboard heater, is connected to a main supply and return line located on the same floor. This configuration allows for independent control of heating zones within each dwelling unit, enhancing occupant comfort and energy efficiency. Furthermore, horizontal systems often facilitate easier maintenance access, as the primary piping is readily accessible without disrupting occupants on other floors.

Horizontal heating systems in residential buildings, characterized by individual heating distribution to each dwelling unit from a centralized source via horizontal piping, present unique challenges and opportunities for effective heat metering.

The heat consuming systems of a residential multi-apartment building are connected to a source of thermal energy – a local boiler house, through an individual heating point. In the heating point of the building, water is prepared for the needs of hot water supply and heating. The heating system is connected according to an independent circuit, the hot water system according to a two-stage independent circuit.

In the basement of the building there is a heating unit, as well as the supply and return lines of the heating system. An apartment-by-apartment radiant heating system is provided on the floors of the building (fig. 3.1). On each floor, floor collectors are installed, located in a special locked cabinet, with the connection of individual apartment circuits (fig. 3.2).

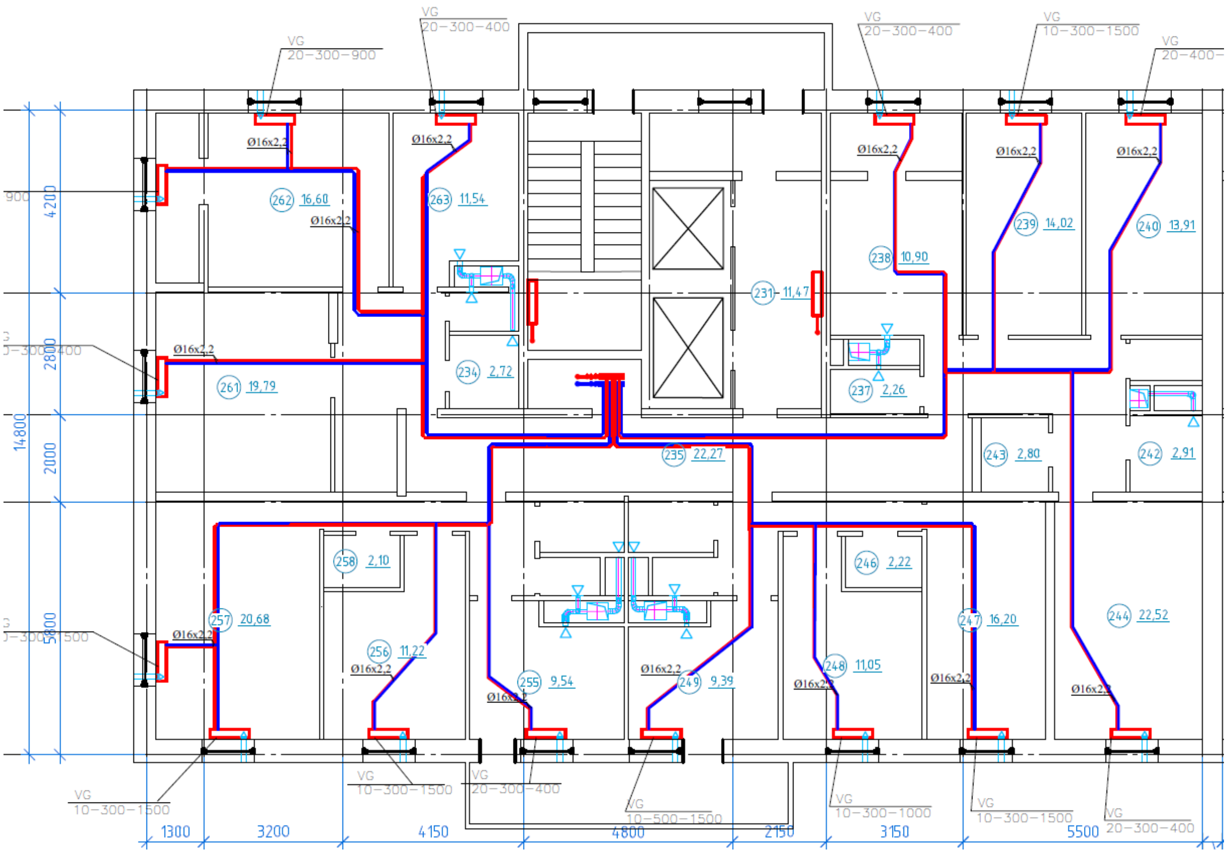

Fig. 3.1. Heating system in residential building