Improving the quality of the air in modern energy-efficient buildings

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Abstract. When operating modern buildings with natural ventilation, it is difficult to maintain the required microclimate balance in the buildings, so mechanical ventilation must be used. This article presents the results of modeling the operation of a supply and exhaust unit with a plate heat exchanger. Based on the analysis, data on energy consumption depending on the method of preheating the supply air are obtained. It is concluded that the least energy-consuming option is to use an air-to-air heat pump.

The operation of a modern energy-efficient building is impossible without properly designed and operated ventilation systems. The increase in the cost of energy (electric, thermal) gives an impetus to the improvement of technological and structural systems of buildings. Installation of airtight windows with increased heat transfer resistance reduces energy consumption during operation by increasing the heat transfer resistance of building envelopes. The rest of the building systems (ventilation, energy, hot water), which affect their energy characteristics, remain at the same level. At this stage, the development of building technologies in relation to engineering systems and building envelopes is a drawback. Approaches to designing an individual building element in isolation from others does not allow optimizing the building structure as a single energy system. First of all, the problems of the building associated with the development of structural, technological and space-planning solutions are solved. By increasing the thermal resistance of the building envelope, a reduction in the level of operating costs of thermal energy for heating is achieved. And despite significant progress in this area, engineering equipment is lagging behind in its development [1, 2].

The use of window structures with increased tightness, while maintaining natural ventilation in the building, leads to negative consequences in the state of the indoor microclimate, which does not meet the norms of humidity and temperature of the indoor air during the heating season, air quality deteriorates. Up to 60% of heat losses account for air exchange in buildings under construction according to existing standards [3, 4]. In the applied design and technical solutions using natural ventilation, this problem cannot be solved. It is necessary to switch to supply and exhaust ventilation with artificial motivation and the use of heat energy recovery.

There is a need to solve the following problems:
Sealed window structures, well-insulated walls almost completely seal the rooms, preventing the air exchange level from being maintained within the normal range. The constant opening of windows for ventilation devalues the original meaning of producing windows with higher thermal resistance. In this case, the use of supply ventilation valves is not a way out. The task of choosing an effective ventilation scheme must be solved by a different approach. The ventilation scheme of the building in the city, by opening the windows for ventilation, leads to a deterioration in air quality in residential premises (especially in apartments on lower floors) and to an increase in the noise level above the established limits.

Requirements for increasing the heat transfer resistance of building envelopes have led to the fact that the maximum component of the heat loss of buildings during the heating period is air exchange (more than 50% of the total level). Saving thermal energy for heating buildings is associated with the return of heat leaving the air from the premises [4].

Solving the problem of air intake using various technical means, for example, local heat recovery systems while maintaining the natural ventilation system, does not lead to improved comfort. The task of maintaining the normative value of air exchange is not properly solved due to the dependence of the level of air exchange on many multidirectional reasons (level of wind load, opening windows, degree of compaction of windows, condition of exhaust shafts, apartment height, outdoor temperature) [5].

While maintaining the natural air exchange scheme, the problem of rational use of energy, including solar energy entering the room, is not solved as a share in the building’s overall energy supply system. Avoiding acceptable microclimate parameters during prolonged and systematic exposure to a person can cause a general and local discomfort, poor performance and poor health while strengthening thermoregulation mechanisms, although the state of health does not worsen [6, 7].

Currently, there is no systematization of the experience of using forced ventilation systems with the recovery of thermal energy of air removed from the premises of multi-storey residential buildings, as well as the features of using regenerative heat exchangers in residential buildings.

The transition to systems with mechanical ventilation of rooms using plate heat exchangers has one characteristic drawback: freezing of the heat exchanger from the exhaust air side with an increase in moisture content in the air. This is due to an increase in relative humidity to saturation when the temperature drops below the dew point, when crystallization of moisture begins. In parallel with the formation of condensate, two effects are observed (an increase in heat transfer due to the heat of the phase transition; a decrease in the heat transfer coefficient due to the liquid layer formed on the plates and a decrease in the cross section of the air channels, which leads to an increase in static pressure losses).

The crystallization temperature at which the water vapor contained in the exhaust air is frozen depends on a number of factors (thermophysical parameters of the exhaust air, the ratio of air flows on the supply and exhaust parts of the heat exchanger, design features of the heat exchanger, heat transfer efficiency).

Currently, there are several approaches to solving the problem of preventing frost recuperators. This is defrosting the entire heat exchanger, partial defrosting (stratification), installing an additional air heater on the supply air side and installing a bypass. All of these methods have both individual and general shortcomings leading to both reduced energy efficiency and increased investment and operating costs.

Using a heat pump allows you to use low-potential energy of the exhaust air, transmitting it to the supply air, Figure 1 [6].
To consider the optimal use of a supply unit with a plate heat exchanger, three options were simulated and calculated (a supply and exhaust unit with a bypass, preheating using an additional heater, preheating using a heat pump):

1. The calculation for the existing supply and exhaust installation of production VTS (1500 m3/h) with a plate recuperator (VTS VS21PCR), with accessories for air filters of cleaning class G4, a supply fan with a capacity of 0.23 kW, an exhaust fan of 0.24 kW and a generated pressure in the ventilation network equal to 100 Pa. The plant efficiency is 57%, when the outside air is heated from minus 14 °C (minus 14 °C is the calculated freezing temperature of this heat exchanger) to plus 4 °C (φ = 13%) and cooling the exhaust air to plus 2 °C (φ = 100%). At minus 36 °C (outdoor temperature), the supply air temperature after the recuperator drops to minus 3.3 °C (φ = 4%), the temperature of the exhaust air decreases to minus 6.9 °C (φ = 100%), the freezing condition is met recuperator. In this installation, to avoid freezing, a bypass channel with a variable width is used. The result is a decrease in the supply air after the recuperator to minus 19.80 °C, exhaust after the recuperator, plus 3.8 °C. To warm the air up to plus 20 °C, it is necessary to spend 20.91 kW, the total energy consumption is 21.38 kW.

2. Using preheating of the supply air (additional air heater to the recuperator), under the previously specified conditions (minus 36 °C), it is necessary to expend 11.56 kW of power. Outside air is heated to plus 4 °C (φ = 3%), the exhaust air is cooled to plus 2 °C (φ = 100%), the heat exchanger efficiency is 56%. To warm the air up to plus 20 °C, it is necessary to spend 8.4 kW, the total energy consumption is 20.44 kW.

3. When using a heat pump, the outdoor air is heated to a temperature of minus 14 °C (the condition of freezing of this heat exchanger) to the heat exchanger, after it has a temperature of minus 4.7 °C (φ = 3%), the exhaust air cools down to minus 5.5 °C (φ = 100%). The necessary costs for heating the supply air are 12.97 kW. The additional costs that go to the heat pump compressor when using Freon R410A (tc = 6 °C) are 0.126 kW. The total energy consumption (necessarily taken into account the fan group) is 13.58 kW [7.8].

The data obtained are summarized in table 1 and presented graphically in the Figure 2, where t1, φ1 - temperature and relative humidity of the supply air to the condenser; t2, φ2 - temperature and relative humidity of the supply air after the condenser; t3, φ3 - temperature and relative humidity of the utilized air to the evaporator; t4, φ4 - temperature and relative humidity of the utilized air after the evaporator.

| №  | t1, °C | φ1, % | t2, °C | φ2, % | t3, °C | φ3, % | t4, °C | φ4, % |
|----|--------|-------|--------|-------|--------|-------|--------|-------|
|    |        |       |        |       |        |       |        |       |

**Table 1.** Experimental temperature and humidity data.
The use of a heat pump in forced ventilation systems of buildings allows solving the problem of expanding the temperature range of the heat exchanger, which will allow rational use of energy conversion. Laying into the project a new approach to ventilation systems will not lead to a significant increase in price at the time of construction.

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