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Enhancing of energetic and economic efficiency of air distribution by swirled-compact air jets

Vasyl Zhelykh[1], Orest Voznyak[2], Yuriy Yurkevych[2], Iryna Sukholova[2], Oleksandr Dovbush[2]

[1]Department of Building Processes Engineering, Czestochowa University of Technology, Akademicka 3 Street, 42-200, Częstochowa, Poland
[2]Department of Heat and Gas Supply and Ventilation, Lviv Polytechnic National University, S. Bandery str., 12, 79013 Lviv, Ukraine
Corresponding author e-mail: orest.voznyak@i.ua

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Abstract
The article is devoted to solving the urgent task of increasing the efficiency of air distribution by swirled-compact air jets to ensure the normative parameters of indoor air. The dynamic parameters of the swirled-compact air jet during its leakage in the alternating mode and the formation of a dynamic indoor climate in the room are determined. For improvement of comfortable conditions in the room and design of energy saving circuits of air distribution it is suggested to use swirled-compact air jets, which flow from the inflow and exhaust heat recuperators with heat recovery of the exhaust air. An energy audit of the ventilation system reconstruction with a recuperator using was carried out. The method of taking into account the fact of application of several measures, which cannot be carried out simultaneously, and discount rate dynamics is proposed.

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1. Introduction

The issues of energy and material saving (Selejdak, 2014; Gumen, 2017), energy efficiency (Klymchuk, 2019) and accounting and cost management are all over-the-top. In the face of an acute economic crisis, careful use of energy is an important priority of the economic policies of European countries. The energy efficiency of the indoor climate system (Zhelykh, 2020) and air quality (Lis, 2019) should be ensured. Maintaining of the standard air parameters that create a comfortable indoor climate in the room is an important social task (Buyak, 2017; Deshko, 2016). The high concentration of CO_2 in the premises results in a deterioration of state of health and a decrease in the working capacity of the personnel. Dynamic indoor climate positively reflects on the state of health of the human body and results in productivity increasing (Voznyak, 2020). There is no doubt that the energy costs of the ventilation system need to be reduced as a result of energy efficiency measures, particularly due to recuperators applying (Adamski, 2010; Adamski, 2017). To achieve the maximum effect, it is necessary to determine the economically feasible level of thermal protection of the microclimate security systems, which should be optimal both in thermal and economic terms.

One of the important tasks for arrangement of premises ventilation is creation of the effective organization of air exchange and in particular air distribution (Dovhaliuk, 2018). At the same time, both the normalized air velocity (Tkachenko, 2020) and the normalized temperature (Basok, 2014; Bilous, 2016) in the working area must be ensured.

These values are normalized for different types of premises and their non-observance can cause deterioration of the people health and affect the operation of the equipment (Lis, 2002). Choice of air supply depends on the purpose of the room, the technological processes that take place in it, and any particular features.

2. Recent research and publications

When designing indoor climate systems for different purpose rooms, the main task is to create comfortable conditions. The microclimate in the production premises depends on the efficiency of work and the quality of manufactured products. It is known that the variable mode of air supply has a positive effect on a person's well-being and efficiency of his work (Kapalo, 2018). However, in production facilities for the adaptation of the apparatus of thermal regulation, improvement of the health state and reduction of fatigue of employees, especially in the monotonous nature of work, hygienically justified by changing one of the parameters, such as temperature or air velocity, that is, to create dynamic indoor climate.

Different ventilation schemes in different purpose rooms and efficiency of air distribution have been considered. However, an analysis of the provision of air exchange in small-sized premises has shown that this is quite a challenge.

There are many different designs of air distributors with high attenuation of air velocity *v* and temperature *t* (Dovhaliuk, 2018). However, insufficient attention has been paid to devices for supplying intake air with swirled-compact air jets. A characteristic feature of the inflow jets created by such air distributors is increased turbulence in comparison with the outlet air jets. So does velocity distribution (Hnativ, 2019). The attenuation intensity of the parameters is characterized by the magnitude of the coefficients of velocity attenuation *m* and the temperature attenuation *n*. The air supply to the upper area of the room is effective by supplying air with a two-jet air distributor (Voznyak, 2020).

When choosing a method of supplying inflow air, it is necessary to take into account the geometric dimensions of the room, the location of equipment, sources of heat and harmfulness, the location of jobs, as well as the possibility of laying the inflow jets on various surfaces. However, the issue of air supply to small industrial premises and the possibility of laying them on the surface of various configurations is remained unresolved.

For the rooms of low volume and height, there is difficulty in supplying of great amount of air to the room while maintaining a low air velocity in the work area (Voznyak, 2020). For this purpose there are suitable the air distribution devices with a low attenuation coefficient. In this case, air distribution devices with a sufficient air distribution area, low initial velocity, and low attenuation coefficient are effective. This is the optimal solution for proper air distribution.

One of the ways to increase turbulence is to use the effect of swirling and laying, however, the laying increases the range of the jet, which is undesirable for small spaces. The mutual attenuation of impulses during the swirling of the air jets results in to the formation of a turbulated air flow that coming from the air distributor into the serviced room.

In addition to providing comfortable conditions in the room, an important role is played by the technical and economic evaluation (Aedah, 2018) of the efficiency of the ventilation systems. Therefore, thermal modernization (Lis, 2019; Lis, 2013) of the ventilation and air conditioning systems is an effective way of reducing energy costs, at condition of inflow and exhaust recuperators application with the utilization of heat of the exhaust air in small industrial premises.

To do this, it should be carried out an energy audit (Myroniuk, 2020; Savchenko, 2020) of ventilation system. in general and of the air distribution in particular. Using of up-to-date methods for assessing of the cost-effectiveness of energy efficiency measures has been taken into account in the latest concept of economic calculations, in particular the recommendation of UNIDO (United Nations Industrial Development Organization). However, these instructions only provide an algorithm for actions that can be applied at the same time.

Based on the review of literature, we state:

1. There is a need to develop a method for calculating a compact jet using a swirling effect, that is, a swirled-compact air stream.
2. There is a need to improve the method of energy audit of the production room ventilation system during its reconstruction in order to take into account measures that can not be carried out simultaneously.

3. Objectives the formulation of the problem

The purpose of the work is to increase the energy and economic efficiency of the air distribution of swirled-compact air jets in the application of inflow and exhaust recuperators with the utilization of heat of the exhaust air in small industrial premises due to the improved method of energy audit.

To achieve this goal, the task was to carry out an energy audit of the production room ventilation system during its reconstruction in order to take into account measures that cannot be carried out simultaneously.

4. Methods, materials and research

It should be noted that the intake and exhaust recuperators (for example Prana-150, Fig. 1) have a characteristic design feature. The axial fan is at a distance from the air outlet that is less than 5 diameters of the inlet pipe. This factor causes swirling of the inflow compact air jet, that is, the air flow exits from the hole by the swirled-compact air jet. Therefore, the attenuation coefficients of the velocity and temperature of the inflowing air jet are reduced, that is, the aerodynamic performance of the device is improved. This reduces the flow rate of the ventilation system and the metal consumption of the system as a whole.

Ability to regulate the air flow rate and heat recovery for its heating is also positive feature of this device.

A model was developed to create a dynamic indoor climate due to automation system. This makes it possible to change the air flow in the ducts and, therefore, to supply the intake air in a variable mode. This ensures a dynamic microclimate in the room serviced area.

The connection of the electric actuator, which is controlled by the automation unit, gives the possibility to smoothly regulate the total air flow in the duct. The flow rate of intake air through the air distributors changes smoothly, the period is given by the automation unit, thus creating a dynamic indoor climate in the working area, which makes it possible to improve the hygienic conditions in the room.

An energy audit of the ventilation system was carried out using a recuperator.

During the reconstruction of the ventilation system, two alternatives variants of the recuperator using were selected: Prana-150 and Prana-200. It is obvious that they cannot be used simultaneously.

The following four energy saving measures were considered:

A – replacement of the mode of operation of the ventilation system from stationary to variable when installing automation;

installation of recuperator with heat recovery of exhaust air:

B – Prana-150;

C – Prana-200;

D – application of the jets laying effect.

Fig. 1. Recuperator Prana-150.

The following solution algorithm is proposed.

Determination of annual energy consumption for the ventilation system needs Q_0, MJ/year for the baseline.

Selection of a list of simple termal renewal measures for this system.

Determination of energy saving ΔQ_i of each thermal renewal measure $\Delta Q_i = Q_o - Q_i$, and therefore the annual savings of K_i, Euro/year. The cost of thermal energy (the value of P_{te}) in Ukraine is 1800-2200 UAH per 1 GCal, ie P_{te}= 17 Euro/GJ.

The amount of heat recovered from the exhaust air stream at the passport value of the efficiency coefficient Prana-150 and Prana-200 is respectively Q_{ut} = 1.25 kW and Q_{ut} = 1.40 kW. This corresponds to Q_y = 40 GJ/year and Q_y = 45 GJ/year during the year.

5. Results and discussion

The results of the calculations are given in Table 1.

Table 1. Characteristics of energy saving measures

№	Measures	Energy costs for the basic option Q_o, GJ/year	After the change Q_i, GJ/year	Energy saving ΔQ_i $\Delta Q_i = Q_o - Q_i$, GJ/year	Savings money $K_i = \Delta Q_i \cdot P_{te}$, Euro/year
1	A	160	114	46	782
2	B	160	120	40	680
3	C	160	115	45	750
4	D	160	152	8	136

Determination of each thermal renewal measure indexes (Table 2) at condition of different magnitudes of the discount rate: r = 0.18 and r = 0.11.

Table 2. Economic indicators of the thermal renewal measures

№	Measures	I_i Euro	K'_i Euro/year	$SPBT_i$ years	$NPVR_i$ r =0.18 Euro	$NPVR_i$ r = 0.11 Euro
1	A	322	782	0.41	+627	+2021
2	B	370	680	0.54	+534	+1673
3	C	420	750	0.56	+632	+1832
4	D	125	136	0.92	+616	+316

Optimization of aggregate thermal innovation options (Table 3). Five columns with the corresponding + and - marks are arranged, taking into account that it is not possible to use Prana-150 and Prana-200 simultaneously.

Table 3. Optimization of cumulative thermal innovation options

№	Measures	Variants				
		I	II	III	IV	V
1	A	+	+	+	+	+
2	B	–	+	+	–	–
3	C	–	–	–	+	+
4	D	–	–	+	–	+
5	I (Euro)	322	692	817	742	867
6	K (Euro)	782	1462	1598	1532	1668
7	$SPBT$ (years)	0.41	0.47	0.51	0.48	0.52
8	$NPVR$(Euro) r=0.18	+627	+1389	+1402	+1298	+1457
9	$NPVR$(Euro) r= 0.11	+2021	+3872	+4207	+3855	+4370

Five aggregate options mean: I – renewal measure A, II - cumulative effect of measures A and B, III - cumulative effect of measures A, B and D, IV - cumulative effect of measures A and C, V - cumulative effect of measures A, C and D. The advantage is estimated by the maximum profit, as evidenced by the value of NPVR. Option V, the combined effect of measures A, C and D has maximum NPVR. So, it is optimal.

The maximum profit is derived from the implementation of energy-saving technologies in the 5th option and amounts to 4370 Euro at condition of the discount rate r = 0.11. The effect is obtained by improving the energy efficiency of the ventilation system, which consists in the simultaneous effect of the following thermal renewal measures: the replacement of the ventilation system from stationary to variable, using of Prana-200 recuperator, application of the jets laying effect.

As a discussion of the results, the effect of the discount rate on the amount of NPVR should be noted. Analysis of Table 3 shows that the profit increases with decreasing discount rate is not proportional. At r = 0.18 NPVR = 1457, and at r = 0.11 - NPVR = 4370. That is, when discount rate r changes 1.6 times, NPVR increases 3 times.

Therefore, the feasibility of both aerodynamic and technical-economic aspects of using of swirled-compact air jets, formed by the Prana-200 recuperator with heat recovery of the exhaust air, in alternating mode is proved. These measures will make it possible to provide comfortable conditions in the production premise and to obtain an economic effect.

The research results can be used in the design of energy-efficient air distribution schemes for small industrial premises.

6. Summary and conclusions

1. Using of the recuperators with heat recovery of exhaust air will allow to get an economic effect 600-1800 Euro depending on discount rate and recuperator brand.
2. The technique of energy audit conducting has been improved. The method of taking into account the fact of application of several measures, which cannot be carried out simultaneously, and discount rate dynamics is proposed.
3. An energy audit of the production premises ventilation system during its reconstruction has been conducted, which showed that the air distribution in the non-stationary mode is efficient because it allows to save energy costs for the ventilation system and has the lowest the simple payback time. The optimum profit from the implementation of energy-saving technologies during operation is 4370 Euro at the following conditions: discount rate $r = 0.11$, replacement of the ventilation system from stationary to variable with automatic equipment, using of Prana-200 recuperator with heat recovery of the exhaust air, application of the jets laying effect.

In future, it is advisable to take into account the impact of production equipment and heat sources on air distribution in a premise. Of interest there are studies on the acoustic characteristics of the proposed equipment.

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通过旋流紧凑型喷气机提高空气分配的能量和经济效率

關鍵詞
空气分配
旋流紧凑型喷气式飞机
动态小气候
热更新
节能

摘要
本文致力于解决通过旋流引导的紧凑型空气射流提高空气分配效率以确保室内空气参数规范的紧迫任务。确定了旋流紧凑型空气射流在交替模式下泄漏期间的动态参数以及室内动态室内气候的形成。为改善室内舒适条件和设计节能送风回路，建议使用旋流紧凑型空气射流，从进、排热换热器流出并回收废气热能。对使用换热器的通风系统改造进行了能源审计。提出了考虑多项措施不能同时实施的实际情况，以及贴现率动态的方法。