Determination of the real energy efficiency of the inlet ventilation air heater and air curtain

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Abstract. The energy efficiency of the heater depends on the U-value at certain energy costs. The article considers the calculation method for the heater performance efficiency in the inlet ventilation and air curtain of the garages for 100 and 75 motor vehicles of the largest industrial enterprise rendering transport services in transportation of loose cargoes, including ores and metal-containing products, large-sized and heavy cargoes, hazardous cargoes etc. The ventilation systems of the surveyed garages are combined with air heating. In order to determine the efficiency of the air handling units, the heat carrier flow through the heater, heat carrier temperature and the air temperature at the inlet and outlet of the air heater, the flow of heated air and the phase currents through the fan motor have been measured. Basing on the instrumental measurements carried out, the calculation results for the air heater thermal performance and the air consumption have been presented, and the determination method for the real U-value and the thermal efficiency of the examined heaters has been provided. Recommendations have also been made to improve their performance. This method is an important hands-on recommendation for the engineers serving air handling units and for the departments developing energy-saving activities for industrial enterprises.

Keywords: ventilation, air heaters, efficiency, U-value, thermal efficiency, air handling units, instrumental measurements, air curtain.

1 Introduction
The legislation obliges to take measures to reduce the consumption level of energy resources and to ensure the gradual achievement of economic benefits using the resources belonging to both buildings and structures and industrial facilities. Determination of the level of losses in engineering structures is considered in papers [1]-[5].

One of the cornerstone components for generating favourable conditions for people to live and work is the effective ventilation of the premises. Assurance of standardized operation of ventilation systems is the primary and crucial task in structural engineering. Ventilation is a kind of complicated schematics, including various elements, such as air inflating units, silencer, air duct, grates, etc. Public and civil ventilation systems are classified by their functional purpose:

1. Supply air systems that supply the exterior air, purified and heated (in the cold season) to the working area of the premises, into the area of human activity;
2. Exhaust systems that remove the exhaust air from where it accumulates;
3. Recirculation systems that reuse all or part of the premises air to reduce cooling (warm season) or heating (transient conditions and cold season) costs [6].

The problem of the ventilation energy efficiency is very crucial nowadays [7]-[22]. One of the main devices used for treatment of the inlet air for the supply to the ventilation system is an air heater - the device warming up the airflow [23]. The principle of the air heater operation grounds on the fact that the heating medium has a higher U-value in respect of the airflow [24].

The energy efficiency of the heater depends on the unit U-value at certain energy costs. In other words, the more heat a unit is capable of delivering at constant energy costs, the higher its efficiency.

In order to calculate the air heater performance efficiency, the inlet ventilation tools and air curtains of the garages for 100 and 75 motor vehicles of the largest industrial enterprise rendering transport services in transportation of loose cargoes, including ores and metal-containing products, large-sized
and heavy cargoes, hazardous cargoes etc., have been investigated. The ventilation systems are combined with air heating. Warm air curtains are foreseen, to prevent the cold air ingress through the gates when vehicles enter.

To determine the efficiency of the air heater, it is necessary to calculate the real U-value. The U-value shows how much heat passes in a unit of time from a more heated to a less heated heating medium through one m$^2$ of the heat exchange surface at a temperature difference [25]. The educational literature is lacking any description of the method to determine the real U-value of an air heater; the passport coefficient data for new installations necessary for the equipment selection is the only provided information.

2 Materials and methods

The reference book on setting up ventilating equipment [26] was used, to derive a formula for the calculation of the real U-value. The resulting real U-value of the air heater was determined through the formula:

$$\kappa_f = \frac{2Q}{F \cdot n \cdot (T_1 + T_2 - t_k - t_a)}$$  \hspace{1cm} (1)

where $Q$ is the heater thermal performance, W; $F$ - area of the heater surface being warmed up, m$^2$; $n$ - number of air heaters; $T_1$ - water temperature at the inlet to the air heater, $^\circ$C; $T_2$ - water temperature at the outlet from the air heater, $^\circ$C; $t_k$ - air temperature at the inlet to the heater, $^\circ$C; $t_a$ - air temperature at the outlet from the air heater, $^\circ$C.

The heater thermal performance as per the amount of heat delivered by the heating medium was calculated through the formula [27]:

$$Q = G \cdot c \cdot (T_1 - T_2), \text{ W}$$  \hspace{1cm} (2)

where $G$ is the flow of the heating medium through the air heater, kg/hour; $c$ - specific heat of water, W·h/(kg·$^\circ$C).

The heater thermal performance in terms of the airflow was calculated through the formula:

$$Q_{air} = 0.278 \cdot L \cdot 1.2 \cdot (t_k - t_a), \text{ W}$$  \hspace{1cm} (3)

where $L$ is the flow of air through the heater, m$^3$/h.

The reference U-value of air heaters is determined according to formulae considering the mass airflow and water flow rate in heater tubes [6], [28].

$$\kappa = 25.5 \cdot (v \rho)^{0.496} \cdot \omega^{0.16}, \text{ W/m}^2 \cdot ^\circ \text{C}$$  \hspace{1cm} (4)

$$v \rho = \frac{L}{3600 \cdot f \cdot n}, \text{ kg/(m}^2 \cdot \text{s})$$  \hspace{1cm} (5)

$$\omega = \frac{0.24 \cdot 10^5 \cdot Q}{f_{h} \cdot (T_1 - T_2) \cdot n}, \text{ m/s}$$  \hspace{1cm} (6)

where $v \rho$ is the mass air flow rate through the heater kg/(m$^2$·s); $\omega$ - water flow rate in the heater tubes, m/s; $f$ - flowing area of the heater for the air passage, m$^2$; $f_{h}$ - flowing area of the heater tubes, m$^2$; $n$ - number of concurrent flows of air and water in the piping layout of the heaters.

The air heater effectiveness is defined according to the formula:

$$\eta = \frac{\kappa_f}{\kappa} \cdot 100\%$$  \hspace{1cm} (7)

The airflow rate was determined with an anemometer and deduced from the heat balance.
To analyze the correctness of measurements and to determine the amount of air, phase currents at the fan motors were measured.

The actual electric power of the fan drive was determined through the formula:

\[ P = \sqrt{3} \cdot J \cdot U \cdot \cos \varphi \cdot \zeta, \text{ kW} \]  

(8)

where \( J \) is the average phase current, A; \( U \) - voltage at the terminals of the motor, V.

3 Results

Within the scope of the survey, measurements of the heating medium flow through the air heater, heat carrier temperature and the air temperature at the inlet and outlet of the air heater, the flow of heated air and the phase currents through the fan motor were carried out.

For the survey period, the ventilation units were operating at the ambient temperature of -5 °C, with the temperature of the heating-system water in the feeding pipeline not exceeding 63 °C.

The measurement results are demonstrated in Table 1.

| Item | Facility under inspection | Water flow, m³/h | Water temperature, °C | Air flow, m³/h | Air temperature, °C |
|------|---------------------------|------------------|-----------------------|----------------|---------------------|
| 1    | P-2 Column 2, Parking garage for 100 motor vehicles | 4.0              | 56.2                  | 31.7           | 33141               | 19.9   | 30.2   |
| 2    | P-1 Column 2, Parking garage for 100 motor vehicles | 4.1              | 56.1                  | 37.5           | 26102               | 20.1   | 30.0   |
| 3    | TZ-3 Column 2, Parking garage for 100 motor vehicles | 3.8              | 56.1                  | 32.2           | 33412               | 19.6   | 29.1   |
| 4    | TZ-1.1 Column 4, Parking place for 75 motor vehicles | 2.2              | 56.2                  | 44.2           | 7860                | 23.7   | 34.9   |
| 5    | TZ-1.2 Column 4, Parking place for 75 motor vehicles | 2.2              | 56.2                  | 44.0           | 8117                | 23.7   | 35.2   |
| 6    | P-3 Column 4, Parking place for 75 motor vehicles | 4.4              | 55.1                  | 35.3           | 31842               | 22.0   | 31.4   |

Fq. (2) was used to calculate the thermal performance of the air heater, forming the backbone for Fq. (3) used to calculate the expected airflow rate through the unit.

Further, the heater operation efficiency was calculated. The calculation results are demonstrated in Table 2.

| Item | 1 | 2 | 3 | 4 | 5 | 6 |
|------|---|---|---|---|---|---|
| \( G \) | 4000 | 4100 | 3800 | 2200 | 2200 | 4400 |
| \( T_1 \) | 56.2 | 56.1 | 56.1 | 56.2 | 56.2 | 55.1 |
| \( T_2 \) | 31.7 | 37.5 | 32.2 | 44.2 | 44 | 35.3 |
| \( Q_i \) | 113953 | 88674 | 105605 | 30698 | 31209 | 101302 |
| \( t_n \) | 19.9 | 20.1 | 19.6 | 23.7 | 23.7 | 22 |
| \( t_k \) | 30.2 | 30 | 29.1 | 34.9 | 35.2 | 31.4 |
| \( L \) | 33037 | 26747 | 33.94 | 8185 | 8104 | 32181 |
| \( P \) | 25 | 11.2 | 5.2 | 5.3 | 5.2 | 18.9 |
| \( F \) | 70.6’6 | 70.6’4 | 70.6’6 | 70.6’2 | 70.6’2 | 70.6’4 |
4 Discussion

The difference between the expected airflow rate through the heater Eq. (3) and the real one obtained through the instrumental measurements amounts to:

- P-1 - 645 m$^3$/h or 2.4 %;
- P-2 - 94 m$^3$/h or 0.3 %;
- TZ-3 - 218 m$^3$/h or 0.7 %;
- TZ-1.2 - 325 m$^3$/h or 4 %;
- P-3 - 13 m$^3$/h or 0.2 %;
- TZ-1.1 - 700 m$^3$/h or 2.2 %.

This leads to the conclusion that the measurements have been duly carried out and with a high accuracy degree. The airflow rate was measured with the AMI 300 anemometer; the heating medium flow through the air heater - with the ACRON-1 ultrasonic flow meter, the temperature was measured with the TK-5.05 surface thermometer. Gaged instruments enlisted in the State register of measuring equipment were applied to inspect the ventilation units.

The data on real and reference U-values of the surveyed heater installations of the supply ventilation system and air curtains are demonstrated in Figure 1.

![Figure 1. Data on real and reference U-values of the heater installations](image)
5 Conclusions
According to the calculations made, it turns out that the efficiency factor for the examined heaters varies from 43 to 47%, which is lower than the optimal value (75-80%). This can be due to the heaters being clogged in the air and water. In the process of operation, it is necessary to perform activities on rinsing the air heaters and appropriate instrumental measurements to determine the efficiency of the air heating units. This method is an important hands-on recommendation for the engineers serving air heating units and for the departments developing energy-saving activities for industrial enterprises.

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