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SYSTEM ANALYSIS OF PROBLEMS AND THE CONCEPT OF INTELLIGENT MICROCLIMATE CONTROL IN REPAIR SHOPS OF MOTOR TRANSPORT ENTERPRISES

Zinnatullin V.V., Sokolova V.V., Vazhdaev K.V.
Ufa State Petroleum Technological University, Ufa, Russia

Keywords: motor transport enterprise, repair shops, microclimate, ventilation, energy efficiency, heat recovery, adaptive control, differentiated air exchange.
Abstract. The problem of ensuring microclimate in repair shops of motor transport enterprises during the heating season is considered. The contradiction between the need for intensive air exchange to remove harmful substances and the high costs of heating supply air is analyzed. Key problems are identified: energy inefficiency, irrationality of ventilation systems, and infrastructure limitations. A comprehensive approach is proposed, based on differentiated air exchange, heat recovery, airflow optimization, and adaptive control using digital twins. Software tools for designing and implementing intelligent systems that reduce energy consumption while complying with sanitary standards are described. Prospects for research in the field of detailed modeling and integration of control systems are outlined.

СИСТЕМНЫЙ АНАЛИЗ ПРОБЛЕМ И КОНЦЕПЦИЯ ИНТЕЛЛЕКТУАЛЬНОГО УПРАВЛЕНИЯ МИКРОКЛИМАТОМ В РЕМОНТНЫХ МАСТЕРСКИХ АВТОТРАНСПОРТНЫХ ПРЕДПРИЯТИЙ

Зиннатуллин В.В., Соколова В.В., Важдаев К.В.
Уфимский государственный нефтяной технический университет, Уфа, Россия

Ключевые слова: автотранспортное предприятие, ремонтные мастерские, микроклимат, вентиляция, энергоэффективность, рекуперация тепла, адаптивное управление, дифференцированный воздухообмен.
Аннотация. Рассмотрена проблема обеспечения микроклимата в ремонтных мастерских АТП в отопительный период. Проанализировано противоречие между потребностью в интенсивном воздухообмене для удаления вредных веществ и высокими затратами на нагрев приточного воздуха. Выделены ключевые проблемы: энергоэффективность, нерациональность вентиляции и инфраструктурные ограничения. Предложен комплексный подход, основанный на дифференцированном воздухообмене, рекуперации тепла, оптимизации потоков и адаптивном управлении с применением цифровых двойников. Описаны программные инструменты для проектирования и внедрения интеллектуальных систем, позволяющих снизить энергопотребление при соблюдении санитарных норм. Обозначены перспективы исследований в области детализированного моделирования и интеграции систем управления.

Maintaining normalized microclimate parameters in vehicle maintenance and repair shops during the heating season presents a complex engineering problem. Its essence lies in the contradiction between sanitary-hygienic and energy efficiency requirements [1, 2].

On one hand, technological processes in the shops are accompanied by the release of harmful substances, necessitating intensive air exchange according to regulations [1].

In the washing bay, these are high humidity, drafts, and chemical aerosols. The battery shop is characterized by the release of sulfuric acid vapors and hydrogen, which forces the use of enhanced ventilation leading to drafts. At welding stations, the main factors are heat emission, convective air currents, and aerosols. The painting and drying booth features solvent vapors, elevated temperatures, and explosion/fire hazards. The forging area is affected by radiant heat, temperature fluctuations, and scale particles. In general repair shops, the microclimate deteriorates due to exhaust gases, dust, and drafts.

On the other hand, during the heating season, removing heated air and supplying cold air from outside is associated with significant costs for its heating, reaching 60-70% of the building's total heat losses [3]. Standard design solutions often fail to resolve this contradiction, leading to a number of problems.

The key problem is energy inefficiency due to the lack of heat recovery [3, 4]. Most ventilation systems in older workshops lack recuperators, leading to direct heat losses and excessive costs for heating ventilation air. This forces personnel to reduce air exchange, degrading air quality and creating health risks [5].

The second significant problem is the irrationality of ventilation systems. Outdated general ventilation schemes do not account for the localization and intermittent nature of harmful emissions [4]. Short-term processes (e.g., engine start-up or welding) require local exhaust, while running the system at constant maximum capacity leads to energy waste. Imbalance between supply and exhaust worsens the situation, causing drafts and reducing system efficiency by 25-40% [7].

The third group of problems is related to infrastructure and technologies. Constant opening of large vehicle doors for car entry leads to massive cold air influxes, disrupting the thermal balance. Inefficient distribution of supply air creates discomfort for personnel ("cold feet") and violates regulatory requirements for temperature distribution along room height. The diversity of pollutants complicates air cleaning, and heat emissions from equipment create an uneven temperature field not accounted for by standard systems.

These shortcomings lead to serious consequences. For personnel: increased risk of occupational diseases, poisoning, and a 15-30% reduction in work capacity [2]. For the technological process: violation of work conditions (especially in painting zones) and accelerated equipment corrosion. For the enterprise's economy: high energy costs (up to 40-50% of total operating expenses) [3], potential fines, increased sick leave and compensation costs, and higher staff turnover [5].

Thus, a systems analysis shows the necessity of transitioning from static systems to intelligently controlled ones. The solution lies in a comprehensive approach based on several key principles.

The first principle is the differentiation of air exchange into background and local, demand-controlled in zones of intensive emissions. This can reduce total air exchange by 30-50% without compromising air quality [4].

The second principle is implementing heat recovery via recuperative units with 60-85% efficiency, reducing energy costs for heating supply air by up to 70% [3].

The third principle is optimizing aerodynamics and air flow distribution. This includes applying air curtains at doors [10] and displacement ventilation schemes to minimize drafts.

The fourth, key principle is implementing automated adaptive control [6, 8]. Such a system, based on data from a sensor network, should regulate ventilation, heat recovery, and heating in real time. Its foundation is a mathematical model of the room's thermal and gas balance, allowing flexible response to changes in the technological process [8].

The central algorithm is a cycle: data collection → model analysis → controller decision → equipment actuation → return to data collection. Such systems demonstrate energy savings of 25-45% while ensuring normative air parameters [9].

Implementing such an algorithm requires a software suite covering all stages-from initial design to real-time operation. This suite can be divided into three key categories.

Category 1: Design and Simulation. A digital model of the workshop is created.

Drawing and 3D Model: nanoCAD or Kompas-3D (for equipment drawings and models). Renga (to create a full building information model with all utilities).

System Calculation: Potok, VENT-Calc, START. These programs select fan capacity, duct sizes, and calculate required heating.

Airflow Simulation (CFD): FlowVision or LOGOS. They show on a 3D model how air will move, where drafts will occur, and how heat and pollutants will distribute. This is needed to find optimal locations for exhausts and supply.

Category 2: Creating Control Logic ("the brains" of the system). Development of algorithms for system decision-making.

Algorithm Development: SimInTech. A virtual prototype of the control system is created, all regulators are configured, and their operation is tested.

Python with libraries (SciPy, NumPy). Used for complex mathematical calculations and creating artificial intelligence algorithms.

Programming PLCs (Programmable Logic Controllers): Programming environments from Russian manufacturers: OVEN, Segment, Tekon, RELSI. Almost all operate on the CODESY platform, which has become an industry standard. Ready algorithms are uploaded here so the controller manages real sensors and dampers.

Category 3: Visualization and Real-time Operation (Interface and Control). These programs show the operator what is happening and perform final analysis for decision-making.

Dispatcher Console (SCADA): MasterSCADA, Trace Mode, KRUG-2000. This is the operator interface: screens show shop layouts, temperature graphs, and allow turning fans on/off. The system also stores all operational history.

Platform for Intelligent Analysis (Digital Twin): Ready-made comprehensive solutions, like those abroad, are not yet available. Therefore, the functionality is created from several parts:

SCADA + Python Integration: For example, MasterSCADA handles visualization and basic control, while a Python server on a separate computer analyzes data in real time, predicts situations, and issues optimization commands.

Specialized Platforms: For example, Platforma IO (from "Tsifra" company) or solutions from GK «AiTi». They help collect equipment data and build a virtual model for analysis.

It is precisely such an intelligent approach, combining energy-saving technologies with adaptive control, that resolves the core contradiction between air quality and energy efficiency, ensuring the required microclimate while reducing operational costs.

Prospects for further research include developing detailed mathematical models for various vehicle maintenance and repair shop zones, conducting feasibility studies for pilot projects, and integrating microclimate control systems with the enterprise's overall energy management system.

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Зиннатуллин Вячеслав Валерьевич – аспирант	**Zinnatullin Vyacheslav Valeryevich** – postgraduate student
Соколова Виктория Владимировна – кандидат филологических наук, доцент	**Sokolova Viktoriya Vladimirovna** – candidate of philological sciences
Важдаев Константин Владимирович – кандидат технических наук, доцент, заведующий кафедрой «Водоснабжение и водоотведение»	**Vazhdaev Konstantin Vladimirovich** – candidate of technical sciences, associate professor, head of the Department of "Water Supply and Sanitation"
Slawa915@yandex.ru	

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