MATHEMATICAL MODEL FOR CONTROLING AND MONITORING OF THE MICROCLIMATE IN CLASSROOMS

Varlamova Lyudmila Petrovna
Doctor of Technical Sciences, professor National University of Uzbekistan,
Rahimova Mohira Muzaffar qizi
Master's student in the field of "Information Systems and Technologies" at the National University of Uzbekistan
Anvarov Diyorbek Umarjon ugli
Trainee-teacher, National University of Uzbekistan

Annotation: This article presents an overview and analysis of mathematical models used for controlling and monitoring the microclimate in educational environments. It emphasizes the importance of maintaining optimal thermal and air quality conditions in classrooms to support students' health, comfort, and academic performance. The study reviews existing systems and introduces models such as PD, PS, TS, and adaptive models that account for dynamic changes in indoor and outdoor climates. A three-level architecture for automated microclimate control systems is proposed, incorporating sensor networks, data processing units, and visualization interfaces. The relevance of the study lies in the need for energy-efficient, human-centered solutions for indoor environmental control in educational settings.
Keywords: Microclimate control, thermal comfort, mathematical modeling, indoor environment, PD model, PS model, TS model, adaptive models, classroom climate, sensor systems, automated regulation, energy efficiency.
Аннотация: В статье представлен обзор и анализ математических моделей, используемых для управления и мониторинга микроклимата в образовательных учреждениях. Подчеркивается важность поддержания оптимальных тепловых и воздушных условий в классах для обеспечения здоровья, комфорта и успеваемости учащихся. Рассматриваются существующие системы и представлены модели, такие как PD, PS, TS и адаптивные модели, учитывающие динамические изменения внутреннего и внешнего климата. Предлагается трехуровневая архитектура автоматизированных систем управления микроклиматом, включающая сети датчиков, блоки обработки данных и интерфейсы визуализации. Актуальность исследования обусловлена необходимостью внедрения энергоэффективных, ориентированных на человека решений для управления внутренней средой в образовательных учреждениях.

Ключевые слова: управление микроклиматом, тепловой комфорт, математическое моделирование, внутренняя среда, модель PD, модель PS, модель TS, адаптивные модели, климат в классах, системы датчиков, автоматическое регулирование, энергоэффективность.
Annotatsiya: Ushbu maqolada ta’lim muassasalarida mikroiqlimni nazorat qilish va boshqarish uchun qo‘llaniladigan matematik modellarga umumiy nazar va tahlil keltirilgan. Sinf xonalarida o‘quvchilarning sog‘ligi, qulayligi va o‘quv faoliyatini qo‘llab-quvvatlash uchun optimal issiqlik va havo sifati sharoitlarini ta’minlash muhimligi ta’kidlanadi. Mavjud tizimlar ko‘rib chiqilib, ichki va tashqi iqlimdagi dinamik o‘zgarishlarni hisobga oluvchi PD, PS, TS hamda adaptiv modellar taqdim etiladi. Mikroiqlimni avtomatlashtirilgan boshqarish tizimlari uchun sensor tarmoqlari, ma’lumotlarni qayta ishlash bloklari va vizualizatsiya interfeyslarini o‘z ichiga olgan uch bosqichli arxitektura taklif etiladi. Tadqiqotning dolzarbligi — ta’lim muassasalarida ichki muhitni boshqarish bo‘yicha energiya tejamkor va inson markazli yechimlarga ehtiyoj bilan bog‘liq.
Kalit so‘zlar: mikroiqlimni boshqarish, issiqlik qulayligi, matematik modellashtirish, ichki muhit, PD modeli, PS modeli, TS modeli, adaptiv modellar, sinfxona iqlimi, sensor tizimlari, avtomatik tartibga solish, energiya tejamkorligi.

The support of microclimate parameters in office or educational spaces has a significant impact on human health, productivity, quality of life, and energy consumption during maintenance. Among the factors of the indoor environment, a set of microclimatic conditions is distinguished, which includes thermal conditions and the composition of the indoor air [1].

To meet microclimate requirements with low energy consumption, it is often necessary to control and manage many microclimate parameters: air temperature and humidity, CO_2 content, using control actions such as air heating (heating), ventilation, humidification, carbon dioxide enrichment, and so on. Due to the high nonlinearity of the physical processes in work and living spaces, classical methods of control theory are either unsuitable for solving the problem of designing microclimate control regulators or are difficult to solve [2,3].

Since educational spaces also have requirements for maintaining the microclimate and are places where it is important to maintain temperature, humidity, cleanliness, and air freshness, students and teachers, spending most of their time in classrooms, are more sensitive to deviations in microclimate parameters [4].

A number of tasks must be solved when creating an automated microclimate control system [5-7]:

- **Analysis of existing parameters** of technological regimes in educational or office spaces, as well as the applied microclimate control and management systems and their functional capabilities;
- **Development of a mathematical model** for spatial control of temperature and humidity parameters in the environment;
- **Development of a model and methodology** for the rational placement of identified sensors in the space;
- **Development of algorithms** for the operation of automated systems based on identified sensors, with the goal of improving regulation quality by increasing the accuracy and reliability of the information;
- **Conducting experimental research** to verify the correctness of the developed theoretical provisions for creating the automated control system, as well as its functionality and effectiveness.

The relevance of the topic of microclimate control and monitoring in office and educational spaces is linked to the problem of creating comfortable or optimal conditions for work and study. Given that there is insufficient attention paid to this issue in the literature, or the focus is mainly on microclimate management in agricultural facilities, creating comfortable conditions for people remains an important task for maintaining health [1]. The types of mathematical modeling used in this field pursue either research or computational goals [8].

Three types of modeling are typically used for simulating microclimate formation processes:

- **Mathematical modeling**, based on solving systems of differential or algebraic equations that describe the thermal, air, humidity, and gas conditions in the space.
- **Physical modeling** in natural conditions or on geometrically similar models, where physical processes are transferred using scaling dependencies.
- **Analog modeling** - a type of physical modeling in which real processes are replaced by others that have formally analogous mathematical descriptions [8].

The microclimate control and monitoring system is based on robotic technologies (Arduino, Raspberry Pi). To create an effective microclimate control system, it is necessary to consider a number of factors and parameters outlined above. In the literature [9], the creation of a smart microclimate control and monitoring system with supply and exhaust ventilation is proposed, based on the use of a breather (air exchange unit). However, this system is not designed for large-volume spaces.

The most relevant system for solving the given tasks is described in [10-12], which has a three-level structure:

1. **The first level** consists of sensors or recorders designed to measure the relative humidity and/or temperature of the surrounding environment.
2. **The second level** consists of microclimate monitoring devices intended for centralized collection, control, storage, and processing of the information coming from the sensors.
3. **The third, upper level** contains devices that display graphical information, mnemonic diagrams for monitoring the parameters.

Types of Mathematical Modeling

- **Model PD**

The PD model predicts the percentage of dissatisfied individuals due to undesirable local cooling (draft). The input data includes air temperature, air velocity, and the turbulence intensity of the airflow[11].

The model equation can be represented as:

$$PD = 3.413(34 - T_a) * (v_a - 0.05)^{0.622} + 0.369 v_a T_u (34 - T_a) * (v_a - 0.05)^{0.622}$$

where T_u is the turbulence intensity, expressed as a percentage (0% indicates laminar flow; 100% means that the root mean square deviation of the airflow velocity over a given period is of the same order of magnitude as the average air velocity); v_a is the air velocity (m/s); T_a is the air temperature (°C).

The equation was derived during a study in which 100 people were exposed to various combinations of air temperature and airflow velocity with different levels of turbulence intensity. For each combination of conditions, the participants were asked whether they felt a draft. Thus, PD represents the percentage of people who reported feeling a draft and, therefore, were dissatisfied with the microclimatic conditions[13].

- **Model PS**

The model is based on the selection of a comfortable air velocity level. The model equation predicts the air velocity that a person would choose at a given air temperature[11].

The model equation can be represented as:

$$PS = 1.13\sqrt{T_{op}} - 0.24 T_{op} + 2.7\sqrt{v_a} - 0.99 v_a$$

where T_{op} is the operative temperature (°C); v_a is the air velocity (m/s).

The equation was obtained from a study involving 50 participants. PS represents the percentage of people who selected a specific air velocity at a given temperature[13].

- **Model TS**

The model equation represents the prediction of thermal sensation using a linear function of air temperature and the partial pressure of water vapor [12]. The equation is written as:

$$TS = 0.24T_a + 0.248p - 6.475$$

where T_a is the air temperature (°C); p is the partial pressure of water vapor (kPa).

- **Adaptive models**

Adaptive models [13-15] allow for the calculation of comfortable conditions in a room, taking into account changes in the external climate. The equations can be applied to both rooms with a microclimate control system and those without it:

$$T_н = 23.9 + \frac{0.295(T_{мно} - 22)}{e - \left[\frac{(T_{мно} - 22)}{24\sqrt{2}}\right]^2}$$

$$T_н = 9.22 + 0.48T_a + 0.14T_{мно}\ T_н = 9.22 + 0.48T_a + 0.14T_{мно}$$

where $T_н$ is the neutral temperature; T_a is the air temperature; $T_{мно}$ is the average monthly outdoor air temperature.

Conclusion

Maintaining a stable and comfortable microclimate in classrooms is crucial for the well-being and performance of students and teachers. The presented models—PD, PS, TS, and adaptive—demonstrate the potential of mathematical approaches to accurately predict thermal comfort and dissatisfaction under varying conditions. Implementing such models within automated control systems can improve regulation accuracy and optimize energy consumption. The proposed multi-level system structure, based on sensor technologies and intelligent algorithms, offers a practical and scalable solution for modern educational facilities. Further research should focus on integrating these models with real-time data and machine learning techniques to enhance adaptability and predictive capabilities.

References

1. Кувшинов Ю.Я. Теоретические основы обеспечения микроклимата помещения. Учебное пособие для студентов специальности 270109. М.: Изд. АСВ, 2007, 184 с.
2. Табунщиков, Ю. А., Бродач М. М. Научные основы проектирования энергоэффективных здании // АВОК. – 1998. – № 1. – С. 6–10.
3. Табунщиков Ю. А. Расчет теплопотерь помещении при раздельном учете конвективного и лучистого теплообмена // АВОК. – 2007. – № 8. – С. 38–44.
4. Гаранин А.В. Разработка систем динамического микроклимата и создание на их основе энергосберегающих режимов работы оборудования: диссертация кандидата технических наук : 05.14.04 / Гаранин Алексей Валентинович; [Место защиты: Иван. гос. энергет. ун-т].- Иваново, 2010.- 209 с.
5. Арутюнов В.А. Математическое моделирование тепловой работы промышленных печей / В.А. Арутюнов, В.В. Бухмиров, С.А. Крупенников. – М.: Металлургия, 1990. – 239 с.
6. Табунщиков Ю.А. Математическое моделирование и оптимизация тепловой эффективности зданий / Ю.А. Табунщиков, М.М. Бродач. – М.: АВОК–ПРЕСС, 2002. – 194 с.
7. Бухмиров В.В. Справочные материалы для решения задач по курсу «Тепломассообмен» / В.В. Бухмиров [и др.]. – Иваново, ИГЭУ, 2009. – 104 с
8. Kokorin O. Ya. Energy-saving technologies for the operation of ventilation, heating and air conditioning systems (VOC systems). -M:, Prospect-N, 2003.
9. TION MAGICAIR BS310 Базовая станция для управления климатической техникой. URL: https://tion.ru/product/magicair/
10. Варламова Л.П., Рахимова М.М. Анализ существующих систем управления микроклиматом. //Proceedings of the 14th International Scientific and Practical Conference “International forum: Problems and scientific solutions”. Melbourne, Australia,16-18.01.2025.#213. –pp.276-280.

11. 11. Varlamova L.P., Rahimova M.M. Analysis of existing models for microclimate management. Journal of advanced Scientific Research (ISSN: 0976-9595). Vol. 5. Issue 1. –pp. 44-46.
12. Системы мониторинга микроклимата Гигротермон: URL: https://gigrotermon.ru/
13. А. В. Карпенко, И. Ю. Петрова - Обзор моделей управления микроклиматом в помещении / Астраханский государственный архитектурно-строительный университет
14. Табунщиков Ю. А., Бродач М. М. Математическое моделирование и оптимизация тепловой эффективности зданий. М. : АВОК-ПРЕСС, 2002. С. 174–175
15. Ferreira A. P., Mose D., Jae C. Oh Thermal Faults Modeling using a RC model with an Application to Web Farms // 19th Euromicro Conference on Real-Time system (ECRTS’07). 2007. P. 113–124