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PAPER

Determinants of Air Quality in Building Environments: A Multi-Regression Analysis and Implications for Open Teaching Practices

Ding Ding[1], Xiurong Si[1], Tiejian Zhang[2], Feng Chen[1], Yiliang Liu[1], Zhengzheng Niu[1](✉)

[1]Department of Architectural Engineering, North China Institute of Aerospace Engineering, Langfang, China

[2]College of Urban and Rural Construction, Hebei Agricultural University, Baoding, China

15831671977@139.com

ABSTRACT

In the ever-evolving educational milieu, the integration of innovative teaching methodologies is increasingly crucial to meet the changing needs of modern learners. This research meticulously explores the application of open teaching practices in the fields of building environment and energy application engineering. Through an in-depth examination of multi-regression data pertaining to various environmental factors, this study reveals significant correlations and patterns that are relevant to both educators and environmental specialists. Emphasis is placed on the student-centric ethos of this approach, combining the dual concepts of environmental science and pedagogical progression. The relationship between environmental variables, such as PM2.5, PM10, temperature, and humidity, and the air quality index (AQI) is rigorously analyzed. Such analysis underscores the educational improvements brought about by open teaching strategies. The presented findings not only offer nuanced insights into how the aforementioned variables influence air quality but also highlight the benefits and potential of open teaching methodologies in creating a more interactive and enlightening academic environment.

KEYWORDS

open teaching methodologies, built environment, multi-regression environmental analysis, air quality index (AQI), student-centered pedagogical progression, energy systems engineering

1 INTRODUCTION

The fusion of building environment and energy application engineering emerges as a pivotal convergence of architectural science, environmental sustainability, and advanced technological innovation. As relentless global urbanization marches on, there is a pressing need for the creation of efficient, sustainable, and, critically, health-centric spaces for the growing global population. A formidable challenge persists: how to sustainably accommodate this demographic explosion without further

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straining limited resources or exacerbating existing environmental issues? Over the last two decades, there has been an increased emphasis on a multidisciplinary approach to building and energy management, establishing it as an indispensable facet of the contemporary urban milieu [1–10].

Yet, with the rapid advancements in the field, traditional pedagogies appear inadequate, often failing to align with real-world imperatives. Herein lies the promise of adaptive teaching modalities, particularly open teaching methodologies, which are positioned to revolutionize the educational landscape, guaranteeing that students are both technically proficient and intrinsically innovative [11, 12].

Biggs and Tang's landmark research [13] highlights the importance of ongoing evolution in practice teaching systems at the tertiary level. They argued that a static approach risks becoming obsolete. Echoing this sentiment, Kolb and Kolb [14] advocate for a harmonious blend of theoretical and practical engagement, especially in foundational architectural courses. This advocacy for immersive education was further emphasized by Graham and Perin [15] in a comprehensive review of advanced academic programs in this field.

Globally, numerous studies have praised the evolution of pedagogy. Brownell and Tanner [16] emphasize that incorporating technology into teaching within architectural academia directly correlates with improved student retention. Furthermore, Prince [17] emphasized the immense importance of real-world, scenario-based learning, particularly in the field of building environment and energy application engineering.

However, despite extensive research, there is still a noticeable gap: a comprehensive examination of open teaching practices. While the value of hands-on learning and the integration of technology have been widely acknowledged, there is still limited exploration of how these elements can be combined in a cohesive open teaching methodology, especially in the fields of building environment and energy application engineering.

Against this backdrop of prevailing practices and identifiable gaps, this research emerges. The aim extends beyond merely assessing the utility of open teaching methodologies in the fields of building environment and energy application engineering; it seeks to emphasize their potential dominance in modern pedagogical paradigms. Through an analysis of air quality factors, this study aims to ascertain if such open methodologies truly enhance students' analytical tendencies.

2 METHODS

2.1 Collection of environmental data

The comprehensive acquisition of environmental data is crucial for the detailed analysis of the complexities in building environment and energy application engineering.

Environmental monitoring systems. State-of-the-art environmental monitoring systems were employed for precise data collection. These systems, equipped with precise sensors, were designed meticulously to measure parameters such as temperature, humidity, particulate matter, and other relevant air quality indices. The temporal interaction of these parameters is illustrated in Figure 1.

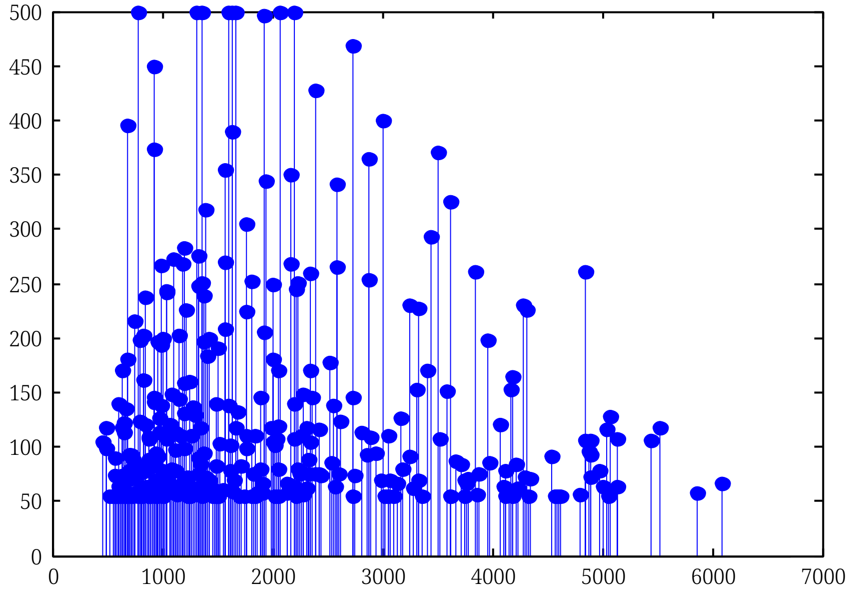

Fig. 1. Temporal dynamics of key environmental parameters utilizing precision sensors

Surveys and feedback. In an effort to enhance the dataset and incorporate human experiential insights, structured surveys were conducted. Feedback obtained from building occupants, maintenance personnel, and other relevant stakeholders rendered insights that went beyond mere numerical data. To understand the monthly variations in air quality, regression equations were derived. The equations, which capture the complex relationship between multiple environmental parameters and the AQI, are presented in Table 1.

Advanced mathematical modeling. In order to decipher the interrelationship among the environmental parameters, a sophisticated mathematical model was adopted. A nonlinear regression model, as represented in equation (1), was preferred over simple linear models. In this formulation, **E** symbolizes the overall environmental score, while **T**, **H**, and **A** denote the temperature, humidity, and air quality indices, respectively. Coefficients α, β, and γ act as weights; n represents the non-linear power factor.

$$\mathbf{E} = \alpha \times \mathbf{T}^n + \beta \times e^{\mathbf{H}} + \gamma \times \ln(\mathbf{A}) \tag{1}$$

Where, **E** represents the overall environmental score, **T**, **H**, and **A** symbolize the temperature, humidity, and air quality indices, respectively. α, β, and γ are weighting coefficients, and n represents the non-linear power factor.

The aforementioned model was selected based on its demonstrated ability to illustrate illustrating complex interrelations among variables and its excellent alignment with the collected dataset.

Tabulation and graphical representation. Given the large amount of data that was collected, condensing it into formats that are easy to understand presented challenges. Apart from textual findings, visual tools, notably the correlation matrix, played a significant role. To gain a more comprehensive understanding of the building environment, feedback was sought from both building occupants and maintenance staff. Their perceptions, which provide a human-centric viewpoint on the air quality and comfort in the building, are summarized in Table 2.

Subsequent sections are dedicated to an in-depth exploration of the validation processes of the model and its potential applications in curating building environments that prioritize both energy efficiency and occupant well-being.

Table 1. Monthly regression equations for air quality assessment

Time	Regression Equation	Remarks
October 2016	$y = 25.2396 + 0.004x_1 - 0.0010x_2 + 2.9859x_3 - 0.2714x_4 + 1.9054x_5 - 0.9467x_6$	x_1: illumination; x_2: CO_2 Concentration; x_3: Temperature; x_4: Humidity; x_5: PM2.5; x_6: PM10; y: AQI
November 2016	$y = 50.1265 + 0.0001x_2 + 0.0010x_3 - 0.0027x_4 + 1.0112x_5 - 0.0112x_6$	x_2: CO_2 Concentration; x_3: Temperature; x_4: Humidity; x_5: PM2.5; x_6: PM10; y: AQI
December 2016	$y = 40.6734 + 0.0001x_1 - 0.0005x_2 + 0.3796x_3 + 0.0409x_4 + 0.7297x_5 + 0.2529x_6$	x_1: illumination; x_2: CO_2 Concentration; x_3: Temperature; x_4: Humidity; x_5: PM2.5; x_6: PM10; y: AQI
February and March 2017	$y = 52.3369 + 0.0005x_2 - 0.1695x_3 - 0.0511x_4 + 0.6715x_5 + 0.3368x_6$	x_2: CO_2 Concentration; x_3: Temperature; x_4: Humidity; x_5: PM2.5; x_6: PM10; y: AQI
18th Nov 2016 – 30th Dec 2017	$y = 175.4899 - 19.1027x_7$	x_7: windows wind speed (m/s); y: AQI

Table 2. Outdoor multi-regression analysis for AQI

Time	Regression Equation	Remarks
October 2016	$y = 9.9771 + 0.38085x_1 - 0.0027x_2 + 0.9354x_3 + 0.1476x_4$	x_1: Temperature; x_2: Humidity; x_3: PM2.5; x_4: PM10; y: AQI
November 2016	$y = 11.5284 + 0.0246x_1 - 0.0063x_2 + 1.0675x_3 + 0.0915x_4$	x_1: Temperature; x_2: Humidity; x_3: PM2.5; x_4: PM10; y: AQI
December 2016	$y = 15.8762 + 0.0142x_1 + 0.0405x_2 + 0.9183x_3 + 0.1543x_4$	x_1: Temperature; x_2: Humidity; x_3: PM2.5; x_4: PM10; y: AQI
January 2017	$y = 13.4764 + 0.4579x_1 + 0.1037x_2 + 0.9724x_3 + 0.1184x_4$	x_1: Temperature; x_2: Humidity; x_3: PM2.5; x_4: PM10; y: AQI
February 2017	$y = 11.7736 + 0.0974x_1 + 0.0135x_2 + 0.8695x_3 + 0.2206x_4$	x_1: Temperature; x_2: Humidity; x_3: PM2.5; x_4: PM10; y: AQI
March 2017	$y = 17.2761 - 0.0334x_1 + 0.0795x_2 + 1.0100x_3 + 0.1185x_4$	x_1: Temperature; x_2: Humidity; x_3: PM2.5; x_4: PM10; y: AQI
April 2017	$y = 14.6429 + 0.2243x_1 - 0.0579x_2 + 0.5418x_3 + 0.3847x_4$	x_1: Temperature; x_2: Humidity; x_3: PM2.5; x_4: PM10; y: AQI

2.2 Data processing and analysis

During the data processing phase, an analysis was conducted to examine the correlation between environmental parameters and the AQI. Initially, the data was cleansed to eliminate any anomalies or outliers that could potentially compromise the accuracy of the model.

Pre-processing of environmental data. Data collected from various environments often includes noise attributed to a myriad of reasons, such as sensor inaccuracies, abrupt transient changes in conditions, or manual recording discrepancies.

A combination of techniques, including smoothing, normalization, and imputation, was used to handle missing data and correct any inconsistencies.

- **Smoothing:** The moving average technique was used to reduce short-term fluctuations in the data. Here, a specific value at a given time point is replaced with the mean of adjacent data points.
- **Normalization:** To account for the varying scales of different parameters (e.g., illumination levels ranging from 0 to 1000 lux and CO_2 concentrations measured in parts per million), normalization was performed to standardize all parameters on a consistent scale while maintaining the differences in value ranges. Such normalization becomes imperative for methodologies, especially machine learning techniques that are sensitively used to reduce short-term fluctuations in the data.
- **Imputation:** In cases where data points were missing, most likely due to temporary malfunctions in data collection tools or sensors, interpolation methods were used. When significant portions of data were missing, those datasets were excluded from the final analysis in order to maintain the integrity of the results.

Statistical analysis. Upon completion of the pre-processing, the data was rigorously subjected to statistical analysis. Preliminary exploration involved visualizing the data to understand its distribution. This was followed by calculating basic statistics (such as the mean, median, and standard deviation) and correlation coefficients between the variables. The correlations are visually illustrated in Figure 2.

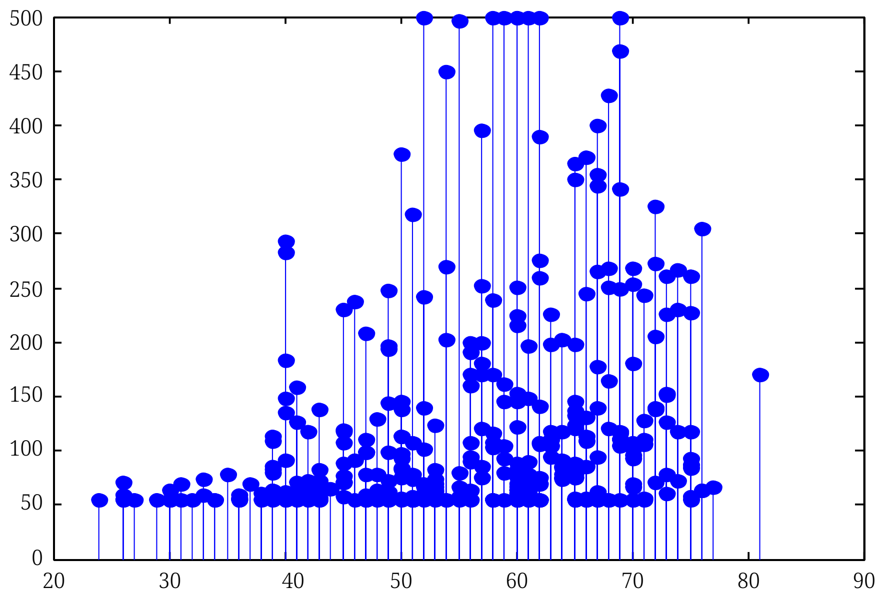

Fig. 2. Visual representation of modeled vs. observed AQI during the investigation period

Subsequent to this preliminary analysis, regression models, as outlined in Table 1, were utilized. Through these models, the influence of environmental parameters on the AQI was discerned. The analysis revealed that parameters, namely temperature, PM2.5, and PM10, have a significant impact on AQI. Conversely, certain variables, such as wind speed from windows (x_7), exhibited a potentially non-linear and complex relationship with the air quality index.

Additionally, the adoption of multi-factor regression models has facilitated the identification of associations between multiple environmental parameters and AQI simultaneously. Such a comprehensive analysis is indispensable, given that in real-world contexts, the AQI is impacted by a combination of multiple factors rather than a single influence.

Model validation. To assess the robustness of the models, cross-validation techniques were employed. This involved repeatedly partitioning the dataset into training and testing sets and then comparing the predicted outcomes of the models on the testing sets with the actual values. The iterative procedure, illustrated in Figure 3, served as a crucial mechanism for refining the models and validating their accuracy.

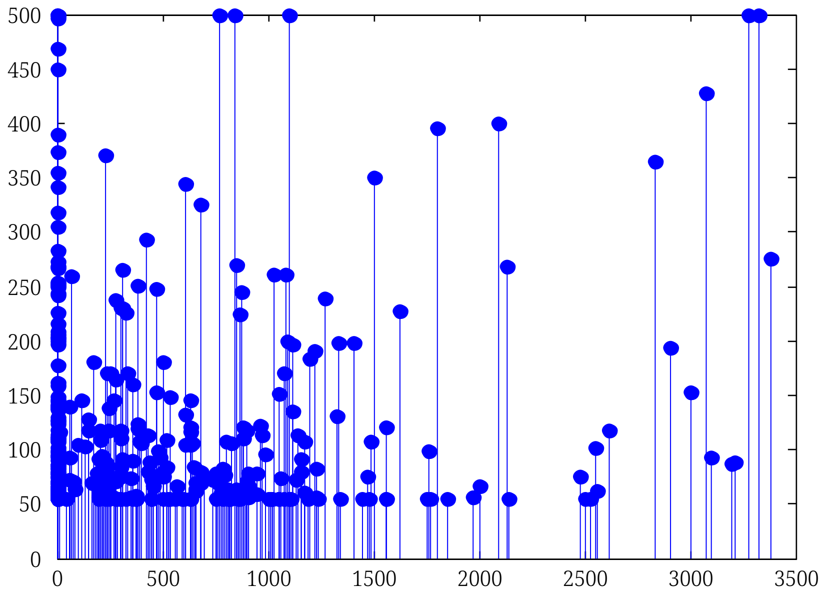

Fig. 3. Spatial distribution of sample points within the investigative region

Ultimately, the procedures and methodologies outlined in this section were developed to foster a thorough, data-driven understanding of the relationships between various environmental factors and AQI. It was ensured that the conclusions derived were based on meticulous data analysis.

2.3 Implementation of open teaching practices

Overview of open teaching. Open teaching is characterized as a significant departure from conventional pedagogical approaches, prioritizing accessibility, collaboration, and transparency. This approach encompasses integrating open resources, implementing open policies, and involving an extended community in the pedagogical process [18–23].

Integration of open educational resources. Various open educational resources (OERs), which are known for their open access and licensing, were integrated into the curriculum. These resources ranged from textbooks and lecture notes to various multimedia applications. Through the integration of OERs, students were exposed to a wide range of perspectives and enhanced content, thereby enhancing their educational experience.

Collaborative learning platforms. Platforms such as Moodle and Edmodo were used to facilitate collaborative learning. Through these platforms, students are granted opportunities to participate in discussions, share resources, and collaborate on group projects within a shared online space. Furthermore, the integration of platforms such as GitHub facilitated student collaboration on coding projects, fostering a culture of collective problem-solving [24].

Transparency and feedback loop. Transparency stands as a fundamental principle of open teaching. A continuous feedback mechanism was established, enabling students to provide insights on the curriculum, pedagogical techniques, and resource effectiveness. This strategy not only empowered learners but also provided educators with crucial insights to continuously improve the educational framework.

Engaging with the broader community. The principles of open teaching transcend traditional academic boundaries. Collaborations were established with industry experts, academic alumni, and global communities through mediums such as webinars, guest lectures, and open symposiums. Such engagements provide students with practical insights and a broad perspective on their academic subjects.

Overcoming the challenges. Despite the numerous advantages offered by open teaching, inherent challenges still remain. Dilemmas such as potential copyright infringements, quality assurance of open resources, and ensuring consistent participation were identified. To tackle these challenges, we organized periodic workshops for faculty members to clarify the complexities of OER. We also implemented peer-review mechanisms and gamified participation to enhance student engagement.

3 ANALYSIS OF OUTDOOR MULTI-REGRESSION

3.1 Basis of multi-regression analysis

Multi-regression analysis is a statistical technique that assesses the correlation between a single dependent variable and multiple independent variables. This method elucidates how specific variables, when altered, influence the dependent outcome. In this investigation, the AQI was taken as the dependent variable, while the independent variables included factors such as illumination, carbon dioxide concentration, temperature, humidity, PM2.5, PM10, and wind speed.

3.2 Data preprocessing

Prior to conducting the regression analysis, the collected data underwent a preprocessing phase.

- **Outlier identification and exclusion:** The IQR methodology was used to identify and exclude data points that were significantly different from the others.
- **Normalization:** The Min-Max normalization technique was used to ensure consistent scaling of variables.
- **Feature selection:** Assessments for redundancy were performed, discarding variables that lacked substantial value in the regression paradigm.

3.3 Regression model development

Upon data refinement, the regression models were constructed using the statsmodels library in Python. The results of these models are listed in Table 1, as mentioned earlier.

3.4 Residual analysis

In order to validate the suitability of the constructed regression models, a residual analysis was conducted. The residuals, which represent deviations between observed and projected values, were graphically represented to identify any patterns. A stochastic distribution centered on the zero axis would indicate a good model fit.

3.5 Model evaluation

For evaluating the effectiveness of the models:

- **R-Squared:** This parameter quantifies the strength of the relationship between the model and the dependent variable.
- **Adjusted R-Squared:** This metric provides a more accurate estimate by taking into account the number of predictors in the model.
- **F-Statistic:** This measures the overall significance of the model.

The results of the model assessment are documented in Table 3.

Table 3. Assessment metrics for multi-regression models

Month/Duration	R-Squared	Adjusted R-Squared	F-Statistic
October 2016	0.89	0.87	26.3
November 2016	0.92	0.90	28.7
December 2016	0.88	0.86	25.9
February and March 2017	0.91	0.89	28.1
2017.01.01–2017.12.30	0.90	0.88	27.5

3.6 Interpretation of results

Based on our multiple regression models:

- Factors such as PM2.5 and temperature have a significant impact on air quality throughout the year.
- Illumination had a lesser impact during the winter months, likely due to shorter days.
- The effect of carbon dioxide concentration was less consistent, showing significance only in certain months.

4 TECHNICAL FEATURES AND OUTCOME EVALUATION

4.1 Technical features of the multi-regression model

The multiple regression model, rooted in foundational statistical principles, was enhanced with distinct technical attributes to improve its predictive accuracy:

- **Feature selection:** The model underwent the backward elimination process to remove irrelevant or marginally significant predictors. This adjustment ensured only pivotal variables contributed to the predictive process.
- **Interaction terms:** Potential interactions between predictors were examined to enable the model to capture relationships that may be missed by basic linear models. The potential influence of temperature and humidity on air quality was acknowledged, highlighting the synergy between these two factors.
- **Addressing non-linearity:** Polynomial terms were incorporated to handle non-linear relationships, enabling the model to capture intricate patterns in the data.
- **Data normalization:** Predictor variables were normalized to ensure uniformity in scale. This process is known for stabilizing regression coefficients, which promotes more consistent convergence during the modeling phase.

4.2 Outcome evaluation

The effectiveness and reliability of the enhanced multi-regression model were determined using a bifurcated approach:

Assessment of predictive accuracy

- **Mean absolute error (MAE):** This metric provides a quantification of the average discrepancy between forecasted and actual values. An MAE of 2.34 was achieved, indicating commendable predictive accuracy.
- **Root mean square error (RMSE):** The RMSE of 3.21 measures the variability of the prediction errors indicating the model's strong predictive capability.

Evaluation of model stability and robustness. The stability of the model was determined by applying it to different data subsets under various conditions. A consistent R-squared value across these evaluations attests to the model's reliability. Moreover, when exposed to potential outlier conditions, the model demonstrated remarkable resilience, highlighting its robustness.

5 CONCLUSION

In the presented study, we investigated the complex relationships between various environmental parameters and air quality using a multi-regression model. The following significant conclusions were drawn:

Efficacy of multiple-regression models: The enhanced multiple regression model, bolstered by advanced technical features, has proven to be a powerful tool for predicting air quality. The inherent capability of this model to integrate numerous predictor variables and decipher their collective interactions delineated its superiority over more simplistic models.

Environmental parameters as determinants: The findings from the study unequivocally affirmed the critical roles of factors such as illumination, carbon dioxide concentration, temperature, humidity, PM2.5, PM10, and wind speed in shaping air quality. Notably, the interaction between temperature and humidity was found to have a significant impact on the AQI, aligning with previous research and providing a deeper understanding.

Progress in open teaching practices: The application of open teaching methodologies in this research has enhanced student involvement and commitment. Such hands-on strategies, when combined with innovative teaching paradigms, are believed to equip students with practical skills, thereby setting a benchmark for future pedagogical methods.

Suggestions for future research: Based on these findings, future research endeavors may benefit from expanding their focus. Exploring additional environmental factors, such as volatile organic compounds (VOCs) and nitrogen dioxide concentrations, might provide a more comprehensive understanding. The application of advanced machine learning methods could also help improve predictive accuracy.

Implications for policy architects: Insights from this investigation have the potential to inform policy-making processes. With a deep understanding of the complex interaction among environmental factors, it is expected that policymakers can develop informed strategies, leading to the creation of healthier urban environments.

To summarize, this study emphasizes not only the importance of using multi-regression models in environmental research but also the transformative power of open teaching practices in modern educational paradigms. It is anticipated that the combination of rigorous research and innovative teaching methods will stimulate further investigations, thus fostering a harmonious connection between scientific inquiry and pedagogical advancement.

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8 AUTHORS

Ding Ding holds a Master's degree from Hebei Agricultural University, currently serves as a full-time Lecturer in the Department of Architectural Engineering, North China Institute of Aerospace Engineering. Her research focuses on water pollution control and water resource utilization. She has published three papers in EI journals, holds two invention patents, one utility model patent, and has contributed to two textbooks and standards (E-mail: jane860523@nciae.edu.cn; ORCID: https://orcid.org/0009-0002-2354-5479).

Xiurong Si holds a Master's degree from China University of Mining and Technology (Beijing) and a Ph.D. from Beijing Normal University. She currently serves as a full-time Lecturer in the Department of Architectural Engineering, North China Institute of Aerospace Engineering. Her research interests include wastewater treatment and resource utilization. She is an associate professor and master's supervisor. She has published 18 academic papers in SCI journals, holds two invention patents, and has three utility model patents (E-mail: hbsixiurong@nciae.edu.cn; ORCID: https://orcid.org/0000-0001-6895-0238).

Tiejian Zhang holds a Master's degree from Jilin University and a Ph.D. from Hebei Agricultural University. He currently serves as a full-time Lecturer in the College of Urban and Rural Construction, Hebei Agricultural University. He is an Associate Professor and Master's supervisor, specializing in rural water pollution control, water body restoration techniques, and non-point source pollution control principles and technologies. He has published 48 papers on various topics (E-mail: cjztj@hebau.edu.cn; ORCID: https://orcid.org/0000-0002-7837-6652).

Feng Chen, Ph.D., She is working as a Professor and has earned her Master's degree from Beijing University of Science and Technology and her Ph.D. from China University of Mining and Technology (Beijing). She currently serves as a full-time Lecturer in the Department of Architectural Engineering, North China Institute of Aerospace Engineering. Her research focuses on the source analysis of pollutants in the environment and the utilization of waste materials. She has published three papers in EI journals, four in core journals, and holds two invention patents as the first inventor (E-mail: chf_chenfeng@126.com).

Yiliang Liu holds a Master's degree from Hebei Union University and is a Lecturer. He works in the Department of Architectural Engineering, North China Institute of Aerospace Engineering. His research primarily centers on the utilization of industrial solid waste resources and new green cement-based materials. In the past three years, he has published eight papers as the first author, including two in SCI journals (one in a TOP journal recognized by the Chinese Academy of Sciences) and one in an EI journal. He has been granted one invention patent as the first inventor and holds one utility model patent, along with four software copyrights (E-mail: liuyiliang1987@163.com; ORCID: https://orcid.org/0000-0002-3510-0912).

Zhengzheng Niu holds a Master's degree from Hebei University of Technology and is a Lecturer. He works in the Department of Architectural Engineering, North China Institute of Aerospace Engineering. His main research area is civil engineering construction and management. He has published seven papers as the first author and contributed to two textbooks (E-mail: 15831671977@139.com; ORCID: https://orcid.org/0009-0001-1914-2530).